Technical Report 783

Requirements for a Device-Based Training and Testing Program for M1 Gunnery: Volume 1. Rationale and Summary of Results

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This report is concerned with several interrelated questions that have arisen because performance requirements and training device capabilities are both expanding. The project began with an analysis of the domain of gunnery stimulus conditions and behaviors. This analysis pulled together information from a variety of sources and organized it into a more comprehensive description of M1 gunnery procedural elements than available from any one existing source. The tactical gunnery domain is described by two lists: (a) a list of tank gunnery conditions and (b) a list of tank gunnery behaviors. These two lists are not independent, but contain intentional redundancies. That is, where conditions create qualitatively different gunnery behaviors (e.g., single target versus multiple targets), the behaviors are segregated as separate activities. On the other hand, some conditions (e.g., target cover and concealment) have more subtle effects (i.e., do not lead to different behaviors) and therefore do not show up as separate activities.

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19. Abstract (Continued)

The gunnery domain description was used to define training objectives and to guide evaluations of the four gunnery devices for both training and testing. Devices included the Videodisc Interactive Gunnery Simulator (VIGS), the arcade-type TopGun device, the Unit Conduct-of-Fire Training (U-COFT), and the Simulated Networking (SIMNET) battle simulation system. Evaluations of device capabilities were based on the fidelity of stimulus and response representation, on instructional features, and on testing capabilities relevant to the gunnery domain. Of particular interest was the identification of potential sources of negative transfer for training and negative correlations between performance on the device and performance on the actual equipment as a testing activity.

Over the entire domain, U-COFT provides a comprehensive and realistic simulation of gunnery conditions and actions. SIMNET can support training of much of the gunnery domain, despite its avowed purpose of training tactical skills. The low-cost gunnery devices (VIGS and TopGun) provide adequate simulations of the conditions and actions related to precision gunnery from a stationary tank. Each of the devices had one or more characteristics that creates negative transfer. Therefore, on-tank experience at both the beginning and advanced stages of training is necessary for training and testing gunnery.

The final process was to combine the evaluations with the training and testing objectives to produce a systematic strategy for training and testing gunnery skills.

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Education and Training

FOREWORD

This report is the first of two volumes describing four related activities focusing on M1 tank crew gunnery performance: (1) an analysis of the domain of tactical gunnery, (2) specification of training and testing objectives, (3) content evaluation of four training devices, and (4) development of a training and testing strategy using those training devices.

This research is a part of the Army Research Institute (ARI) task entitled "Application of Technology to Meet Armor Skills Training Needs." That task is performed under the auspices of ARI's Armor Research and Development Activity at Fort Knox, whose mission includes optimizing the use of armor training devices for readiness in gunnery and tactics.

The proponent for this research is Training and Doctrine Command (TRADOC), and the user is U.S. Army Armor Center (USAARMC) (Letter of Agreement with ARI entitled "Establishment of Training Technology Field Activity, Fort Knox, Kentucky," 4 November 1983).

Plans for, and progress on, this project have been disseminated through briefings to the Assistant Commandant, Technical Director, and Department Heads of the U.S. Army Armor School at Fort Knox. Project scientists also made informal presentations to the Director of the Armor School Directorate of Training Developments (DOTD), and to ORSA (Operations Research and Systems Analysis) personnel. Access to data sources was provided by Gary Elliot of the Directorate of Evaluation and Standardization and by Robert Cisco of the Office, Chief of Armor. Additional presentations are being planned for DOTD personnel and the American Psychological Association. Advance copies of the report have been sent to PM-TRADE and the TRADOC Deputy Chief of Staff for Training.

The research provides information complementary to current emphasis and proposals regarding armor device training strategies. The gunnery training objectives, summaries of device capabilities and limitations, and procedures for developing device-based training will, we hope, be useful at all levels of training and testing development for armor crews.

EDGAR M. JOHNSON
Technical Director

REQUIREMENTS FOR A DEVICE-BASED TRAINING AND TESTING PROGRAM FOR M1 GUNNERY:
VOLUME 1. RATIONALE AND SUMMARY OF RESULTS

EXECUTIVE SUMMARY

Requirement:

Gunnery weapons and training device technology have undergone a radical shift in capabilities because of the availability of small, low-cost computers. For weapon systems, the advanced features of the M1 tank create greater fighting potential but also create more extensive crew responsibilities. Training devices have also become more complex with new stand-alone devices that attempt to represent larger segments of the gunnery domain. In this report, we examine four such computer-based devices that can be used to train M1 gunnery skills: the Videodisc Interactive Gunnery Simulator (VIGS), the arcade-type TopGun device, the Unit Conduct-of-Fire Trainer (U-COFT), and the Simulated Networking (SIMNET) battle simulation system.

This report is concerned with several interrelated questions that have arisen because performance requirements and training device capabilities are both expanding. First, given the technological sophistication of the M1 tank, what is the domain of stimulus conditions and behaviors that relate to tank gunnery? Second, what are the training requirements for tank gunnery? Third, what are the capabilities of the four computer-based devices for providing training? Fourth, can an integrated program be designed to train gunnery skills with those devices?

No quality training program can exist without the capacity for measuring students' progress. Therefore, two questions arise about performance measurement capabilities of the new devices. First, can devices determine gunnery performance deficiencies? Second, is performance on the device predictive of performance on actual equipment?

Procedure:

The project began with an analysis of the domain of gunnery stimulus conditions and behaviors. This analysis pulled together information from a variety of sources and organized it into a more comprehensive description of M1 gunnery procedural elements than were available from any one existing source. For purposes of training and testing, we confined our attention to crew duties--one crew member at a time--but included events, conditions, and actions that are a part of the context of a crew operating in a platoon mission. This added significantly to the performance requirements that are required on a more "pure" gunnery (i.e., gunnery marksmanship) exercise such as Tank Table VIII. Thus, our terminal objective for gunnery was not confined to "pure" gunnery, but was expanded to include gunnery conditions and behaviors associated with a tactical context. We referred to our domain as M1 <u>tactical gunnery</u>. Our gunnery domain description became the foundation for (a) deriving training and testing objectives and (b) evaluating device capabilities.

Our partitioning of the gunnery domain into training and testing objectives was based on a hierarchical analysis approach. According to this approach, dependencies among performance requirements are identified and training objectives are organized to ensure that prerequisites are presented first. To supplement these training objectives, we evaluated feedback requirements and determined measurement specifications for the objectives.

The gunnery domain description was also used to guide evaluations of the four new gunnery devices for both training and testing. Evaluations of device capabilities were based on the fidelity of stimulus and response representation, on instructional features, and on testing capabilities. Of particular interest was the identification of device features that might cause negative transfer of training and/or reductions in the correlation between performance on the device and performance on the actual equipment as a testing activity.

It should be noted that these device evaluations were not based on experimental transfer of training studies. They were based on detailed observation of device performance characteristics using domain description and instructional features inventories.

The final process was to combine the evaluations with the training and testing objectives to produce a systematic strategy for training and testing gunnery skills.

Findings:

This volume of the report emphasizes our analytic rationale and presents result summaries for each of these research activities. The second volume (Morrison & Hoffman, 1987) presents appendixes that describe in detail the results from each activity.

The tactical gunnery domain was described by two lists: (a) a list of tank gunnery conditions and (b) a list of tank gunnery behaviors. These two lists were not independent, but contained intentional redundancies. That is, where conditions created qualitatively different gunnery behaviors (e.g., single target versus multiple targets), the behaviors were segregated as separate activities. On the other hand, some conditions (e.g., target cover and concealment) have more subtle effects (i.e., do not lead to different behaviors) and therefore did not show up as separate activities.

Gunnery conditions were organized along the following 22 "parameters":

Target type	IFFN	Formation
Target movement	Enemy activity	Special engagement requirements
Target cover/ concealment	NBC conditions	Space
Target array	Equipment status	Visibility
Target orientation	Number of crewman	Terrain grade
Target range	Supply shortages	Terrain vegetation
Target sector	Mission	Cultural features
	Fire control	

Gunnery behaviors were analogously organized into the following 11 "activities":

Prepare stations for operation
Perform prepare-to-fire checks
Acquire targets
Engage single target with main gun
Adjust fire
Engage single target with the coax
Engage multiple targets with main gun
Engage target with Cal .50 (including simultaneous with main gun)
Engage target using degraded gunnery techniques
Engage main gun target(s) from the TC position
Assess results of engagement

The activities were further divided into parts and options, with behavior requirements listed in detail for all four crew members.

The analysis of training and testing objectives indicated that, in general, the gunnery domain was wide but not very deep. By wide, we meant that the student must know how to perform a wide range of disparate activities. By its lack of depth, we meant that performance is not dependent on a lot of prerequisite knowledge and skill. These structural characteristics of the gunnery domain had some general implications for the acquisition and retention of gunnery skills. For one, initial train-up of gunnery skills should be relatively fast since training is not dependent on complex layers of prerequisite skills. However, skill sustainment may be a problem for two reasons: (1) the sheer extent and diversity of the domain and (b) the predominance of procedural tasks, which research has indicated are especially susceptible to decay (e.g., Schendel, Shields, & Katz, 1978). The hierarchical analyses specified only a proportionally small number of required sequences in instruction. Additional rules for sequencing instruction were derived from a training strategy that we termed "progressive elaboration" (Bessemer, personal communication, December 1987). According to this strategy, students start training on some basic procedure (e.g., precision gunnery) and add variations and elaborations as basic skills are mastered.

Analysis of measurement requirements emphasized consideration of the kind of feedback that is most likely to be required to improve deficient performance. Feedback was focused on any of three areas: (a) knowledge (i.e., facts or rules) needed to conduct the procedure, (b) behavior techniques, and (c) outcomes of behavior. Specification of which to use depends on decision-making or cognition skills required, on the difficulty of the motor skills required, and how closely outcomes are tied to behavior. For example, because of the number of factors influencing the fall of a round, target hits is not a very good indicator of the cause of skill deficiencies in tracking.

Evaluation of the devices was conducted with respect to fidelity features, instructional features, and testing capabilities. These evaluations were rational assessments of device capabilities with respect to tactical gunnery domain performance elements, instruction requirements, and testing capacities. Several of the more general conclusions from these analyses are presented below:

1. Over the entire domain, U-COFT provides a comprehensive and realistic simulation of gunnery conditions and actions. Considering the purpose and cost of U-COFT, this is not an unexpected result.

2. Despite its avowed purpose to train tactical skills, SIMNET can support training of much of the gunnery domain. In terms of gunnery conditions, SIMNET provides a simulation of the mission requirement parameters (e.g., fire control, movement formation) not supported by the other simulators. In terms of actions, SIMNET provides a sufficient simulation of many crew gunnery activities, and it is the only computer-based simulator to provide practice on driver and loader activities.

3. The low-cost gunnery devices (VIGS and TopGun) provide adequate simulations of the conditions and actions related to precision gunnery from a stationary tank. While this activity is but a small part of the gunnery domain, precision gunnery skills are regarded as prerequisite to many of the other aspects of gunnery.

4. None of the devices provides worthwhile instruction or practice of secondary gunnery functions (prepare for operations and prepare for fire procedures). Simulation of the target acquisition and identification phases of gunnery is also deficient for all four devices.

5. U-COFT and VIGS exercises start with some sort of preview that includes a description of the to-be-engaged target(s) and the conditions under which the engagement is to be conducted. These previews encourage the student to preset switches on the Fire Control Panel. Not only is this inappropriate practice, but it may also lead to the unsafe habit of arming the weapons and the laser range finder before the TC issues a fire command.

6. Effective use of devices requires that they allow for the selection of exercises. All devices have some capabilities in this regard, but SIMNET appears more cumbersome to use.

7. U-COFT and TopGun appear superior to both SIMNET and VIGS in allowing an instructor to control (start, stop, freeze, replay) practice engagements.

8. Except for U-COFT, automated scoring features on the devices are limited in number and tend to be outcome oriented. Outcome measures are generally the least useful for diagnosing performance deficiencies. Using any of the devices to determine the causes of performance deficiency would require the close involvement of an instructor.

9. On-tank experience at both the beginning and advanced stages of training is necessary to train and test the entire domain of gunnery.

Utilization of Findings:

The research provides information that should be useful to the Armor training community. Of particular interest are the gunnery training objectives and the summary of device capabilities and limitations. In addition, the research provides a model for the development of device-based training that should apply to other Army training situations.

REQUIREMENTS FOR A DEVICE-BASED TRAINING AND TESTING PROGRAM FOR M1 GUNNERY: VOLUME 1. RATIONALE AND SUMMARY OF RESULTS

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REQUIREMENTS FOR A DEVICE-BASED TRAINING AND TESTING PROGRAM FOR M1 GUNNERY:
VOLUME 1. RATIONALE AND SUMMARY OF RESULTS

CHAPTER 1

INTRODUCTION

The Army is in a constant struggle to maximize tank crew proficiency while responsibly managing training costs. As a result, the past 15 years have seen a proliferation of tank gunnery training devices. These devices are designed to significantly increase gunnery practice by supplementing costly live-fire practice. Fingerman, Wheaton, and Boycan (1979) identified 21 such devices for training skills relevant to the M60A1. The majority of devices were tank-appended, i.e., attached to the tank itself. Tank-appended devices provide an inexpensive alternative to live fire by indicating a gunner's aiming point at the time he squeezes the trigger. For example, the M55 Laser projects a visible beam on a target board. The Telfare device is a caliber .50 machine gun, mounted in parallel with the main gun and fired at scaled range targets. Other devices were stand-alone devices that represent selected tank displays and controls, providing practice for various aspects of gunnery (e.g the Wiley Burst-on-Target trainer). Like the tank-appended devices, their emphasis is on providing practice and feedback in tracking and aiming the main gun with the power control handles.

Both gunnery weapons' technology and training device technology have been constantly evolving with the 1980s, witnessing a radical shift in capabilities because of the availability of relatively low-cost computers. For weapon systems, the advanced features of the M1 tank create greater capabilities and also more extensive crew responsibilities. For instance, the digital ballistic computer instantaneously corrects for cant, wind, and tube wear sources of error. This increase in weapon capability also increases the crew's responsibility to know how to detect failures in the ballistic computer and what to do in case of such failures. Training devices also have become more complex with new stand-alone devices that attempt to represent larger segments of the gunnery domain. In the present report, we examine four such computer-based devices that can be used to train M1 gunnery skills: the Videodisc Interactive Gunnery Simulator (VIGS), the arcade-type TopGun device, the Unit Conduct-of-Fire Trainer (U-COFT), and the Simulated Networking (SIMNET) battle simulation system.

This report is concerned with several interrelated questions that have arisen because performance requirements and training device capabilities are both expanding. First, given the technological sophistication of the M1 tank, what is the domain of stimulus conditions and behaviors that relate to tank gunnery? Second, what are the training requirements for tank gunnery? Third, what are the capabilities of existing devices to provide training? Fourth, can an integrated program be designed to train gunnery skills with those devices?

No quality gunnery training program can exist without capabilities for measuring the progress of students. A fundamental purpose of the training devices is to provide feedback concerning main gun control. Therefore, two questions arise about performance measurement capabilities of the new devices. First, can these devices identify actual gunnery performance deficiencies. Second, is performance on these devices predictive of performance on the M1 tank?

Our plan for addressing these questions is represented in Figure 1-1 by a flow diagram interrelating four research activities.

The project began with an analysis of the domain of gunnery stimulus conditions and behaviors. This analysis is presented in Chapter 2. This analysis pulled together information from a variety of sources and organized it into a more comprehensive description of M1 gunnery procedural elements than available from any one existing source.

Our gunnery domain description became the foundation for (1) deriving training and testing objectives and (2) evaluating device capabilities. An initial activity used in deriving training and testing objectives was the identification and review of information from which we could discern specific areas of gunnery that may be particularly difficult to perform. These areas could then be given special attention in training development. Chapter 3 describes our analysis of three sets of information that were available and our conclusions regarding gunnery performance deficiencies.

Our partitioning of the gunnery domain into training and testing objectives was based on a hierarchical analysis approach. This approach looks for dependencies among performance requirements and organizes training to insure that prerequisite objectives are presented first. Chapter 4 begins with a description of this approach and illustrates its application to the M1 gunnery domain. Chapter 4 continues with presentation of considerations related to testing the knowledge and skills of the gunnery domain. This section emphasizes the need for more than a superficial analysis of performance measurement requirements. Example measurement specifications are presented.

The gunnery domain description was also used to guide evaluations of the four new gunnery devices for both training and testing. Evaluations of device capabilities were based on the fidelity of stimulus and response representation, on instructional features and on testing capabilities relevant to the gunnery domain. Chapter 4 describes fidelity and instructional features criteria and then presents summary evaluations of the devices for training. Chapter 5 presents testing requirements and summary evaluations of the devices for testing applications. Of particular interest was the identification of potential sources of negative transfer for training and negative correlations between performance on the device and performance on the actual equipment as a testing activity.

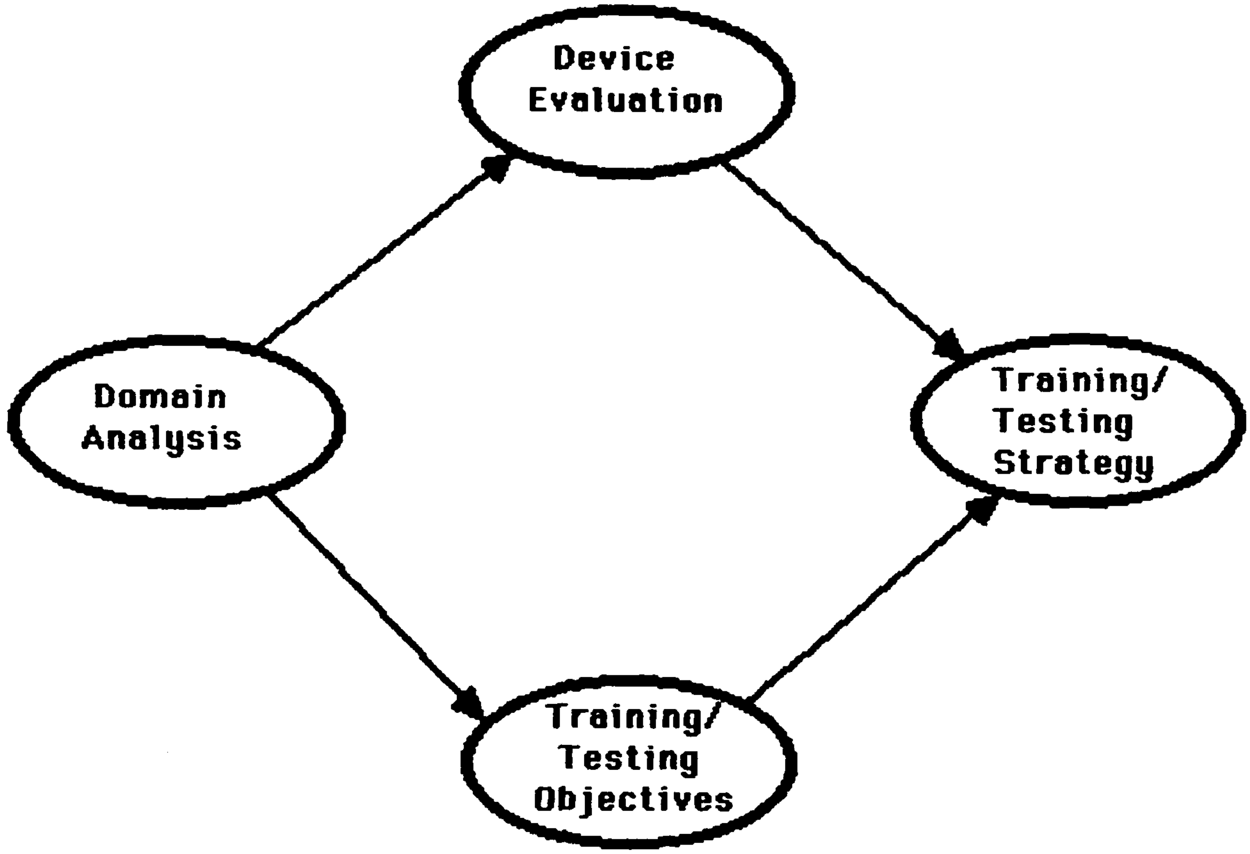

Figure 1-1. Flow of research activities in the present project.

The final process was to combine the evaluations with the training and testing objectives to produce a systematic strategy for training and testing armor skills. Chapter 7 presents a concept strategy for training and testing gunnery skills.

In execution, the activities described above were not discrete, as issues raised in "later" steps created new perspectives for "earlier" steps. For example, revisions and reorganizations of the gunnery performance domain were on-going throughout the effort. This willingness to go back and forth between phases of the effort was limited by one important principle: Training and measurement needs, not device capabilities, should drive training design. Thus, reorganizations of the gunnery domain at various stages during the research were based on increased understanding of the relationships among gunnery behaviors and were not dictated by device presentation capabilities or limitations.

This volume of the report emphasizes our analytic rationale and summary result summaries for each of these research activities. The second volume (Morrison & Hoffman, 1987) presents appendixes that describe in detail the results from each activity.

CHAPTER 2

GUNNERY TASK PERFORMANCE DOMAIN

The initial requirement of developing and evaluating any training strategy is a complete description of the performance domain. Such a description becomes a check list for determining coverage of training presentations and practice exercises. When designing instruction using actual equipment, the equipment itself provides a built-in safeguard. Incorrect or incomplete instruction is immediately exposed by incompatible machine demands. On the other hand, when training is to be conducted on simulators, much greater care is needed in describing the performance domain. Incomplete or ambiguous domain specification can lead to mistakes in device design that are discovered only after negative transfer of training effective come to light. In order for this project to reach the twin goals of (1) evaluating M1 gunnery training devices, and (2) designing training sequences utilizing those devices, a complete definition of the gunnery domain was needed. In our review of Army doctrine and research materials, we found no one source that pulled together all of the gunnery performance information. Therefore, we decided to assemble in one document an M1 gunnery domain description. The resulting effort was a three-fold analysis of (1) the major activities typically associated with tank gunnery (e.g., fire main gun, fire coax, multiple targets, subsequent fire commands, etc.), (2) the detailed performance elements required for each activity (e.g., turn on main gun switch, close ammo doors, announce "cease fire"), and (3) the conditions in which the activities are performed (types of targets, target motion, etc.). As a result the gunnery performance domain was defined as an inventory of every gunnery performance element with the elements partitioned into major activities. This inventory was augmented by a list of conditions in which gunnery is performed. The process and resulting domain are described in the remainder of this chapter.

Background Materials

Our analysis of the M1 gunnery domain began with FM 17-12-1, Tank Combat Tables (1986). This field manual describes doctrine for the major activities of tank gunnery including target acquisition, platoon fire distribution and control, as well as individual tank crew duties during main gun and machine gun engagements. In addition, it includes a series of tank gunnery exercises, Tank Gunnery Tables. Tank Tables I to VII present individual exercises leading up to main gun firing at a variety of targets from a single moving tank in Table VIII. Tank Gunnery Tables IX to XII introduce coordination with one other tank in a section and three other tanks in a platoon. Table 2-1 summarizes these gunnery exercises.

The Tank Gunnery Tables are supplemented in FM 17-12-1 with a series of Tactical Tables that require crews to practice special techniques that introduce skills beyond the physical limits of the ranges used for the Gunnery Tables. These tables are also arranged for one tank, two tanks in

Table 2-1

Summary of M1 Gunnery Tables

Table	Exercise	Level
I	Basic Gunnery Skills	Individual
II	Basic Gunnery Skills	Individual/Crew
III	Basic Training Course	Crew
IV	Basic Qualification Course[a]	Crew
V	Machine Gun Training	Crew
VI	Main Gun Calibration and Preliminary Training	Crew
VII	Intermediate Training Course	Crew
VIII	Intermediate Qualification Course	Crew
IX	Advanced Training Course	Section
X	Advanced Qualification Course	Section
XI	Advanced Training Course	Platoon
XII	Advanced Qualification Course	Platoon

<u>Notes</u>. Tables IV, VIII, X, and XII are "gates" in that soldiers must qualify on them to be eligible for subsequent tests. Gun calibration (Table VI) must be performed prior to main gun Tables VIII, X, and XII. Also, training courses (Tables IX and XI) must be completed prior to attempting qualification on X and XII, respectively.

STRAC (FM 17-12-1, 1986) guidelines allocate the follow numbers of main gun rounds per crew per gunnery table. These are multiplied by the number of firings per gunnery year to provide the annual totals:

3 x Table VI screening test:	9 rds SABOT (TPDS-T)	
1 x Table VI (excluding screening test):	10 rds SABOT	4 rds HEAT-TP-T
1 x Table VII:	9 rds SABOT	6 rds HEAT
3 x Table VIII:	48 rds SABOT	18 rds HEAT
Annual Totals:	76 rds SABOT	28 rds HEAT = 104 total

a section, and four tanks in a platoon. Tactical Tables A, B, D, E, G, and H are various movement, formation, action, and contact drills for individuals, crews, sections, and platoons. Although gunnery is not included in these exercises, they illustrate the context in which gunnery engagements will occur, and thus represent important conditions for gunnery. In contrast, Tactical Tables C, F, and I do involve gunnery engagements but cannot be conducted under the live-fire range conditions of the Tank Gunnery Tables. Instead, these exercises are conducted with MILES gunnery simulation equipment. These tactical engagement exercises are briefly summarized in Table 2-2.

Given the breadth of FM 17-12-1, coordination among tanks must be included as part of the gunnery domain. For purposes of training and testing, we want to confine our attention to include crew duties, one crew member at a time, but to include events, conditions, and actions that are a part of that crew functioning in the context of a platoon mission. This introduces the need to attend to mission requirements, tank sector assignments, platoon leader fire commands, TC reporting, and a tank's position and movement relative to its companion tanks while engaging and being engaged. This adds significantly to the performance requirements that are required on a more "pure" gunnery exercise like Table VIII. Thus, our terminal objective for gunnery is not confined to "pure" gunnery (or marksmanship as defined by Wheaton, Fingerman, and Boycan, 1978), but is expanded to be gunnery in a tactical context. To emphasize this point, we will refer to the domain as M1 tactical gunnery. Some of the terms that we have adopted to describe the domain of tactical gunnery are defined below. Included are the primary literature sources we used for each aspect of the domain.

Primary Functions. Tank gunnery is usually described categorically, differentiating a number of topics. These include main gun single, multiple and simultaneous targets, coax targets, fire adjustment and subsequent fire commands. The principle literature source for these primary functions was the Tank Combat Tables (FM 17-12-1).

Secondary Functions. Tank gunnery performance is always preceded by gunnery preparations including prepare for operations (PREOPS) procedures and prepare to fire (PREFIRE) checks. Many of these procedures give information needed for gunnery (e.g. operational status of the tank). Others are important influences on tank performance (boresighting). Because of their necessity for performance, these were included in our definition of the tank gunnery domain. The principle source for secondary functions was the M1 Operators Manual (TM 9-2350-255-10-2).

Degraded Mode Techniques. The technological sophistication of the M1 creates an extensive set of possible system failures and degraded mode techniques for adapting to these failures. The array of degraded mode techniques was included in our gunnery domain. Sources of these conditions included FM 17-12-1, the M1 Degraded Mode Gunnery: Booklets 2 and 3 (Kraemer, 1984) and the degraded mode gunnery courseware for the hand-held tutor prototype developed for ARI by Educational Testing Service.

Table 2-2

Summary of Tactical Tables C, F, and I

Table	Task
C.	Crew Reaction Exercises
	1. Engage targets simultaneously with all three machine guns.
	2. Engage helicopter.
	3. Engage tanks to rear.
	4. Engage surprise target at close range.
	5. React to ambush.
	6. Engage sniper with dismounted loader (tank stopped at obstacle).
F.	Section Reaction Exercises
	1. Engage multiple targets with machine guns and main gun.
	2. Engage multiple machine gun targets.
	3. React to ambush.
	4. React to OPFOR tank platoon.
	5. Engage patrol and sapper (tanks stopped by mine field).
	6. Engage wheel vehicles and helicopter
I.	Platoon Reaction Exercises
	1. Multiple machine gun targets.
	2. Engage targets of opportunity (regimental CP).
	3. Engage aerial targets (helicopter).
	4. Engage supply convey.
	5. React to ambush.
	6. Engage targets of opportunity (artillery).
	7. Engage targets from hasty battle position.

Note. Across the three levels of training, there are a number of parallel exercises:

(a) Multiple machine gun: C1, F2, I1.
(b) Engage helicopter: C2, F6, I3.
(c) Close, surprise targets: C4, F4, I2, I6.
(d) React to ambush: C5, F3, I5.
(e) Engage wheeled vehicles: F6, I4

Conditions. Certainly, there are environmental conditions that to varying degrees influence gunnery. Delineation of these conditions must be included in any specification of the gunnery domain. Considerable effort had been devoted to defining the domain of gunnery behaviors for the M60 series tank based on identification of gunnery conditions. Kraemer, Boldovici, and Boycan (1975), updated by Wheaton, Fingerman, and Boycan (1978), identified specific gunnery objectives based on combinations of eleven conditions. Kraemer et al. (1975) identified 225 objectives; Wheaton, et al. (1978) identified 266. These objectives were then clustered into similar types by examining the behavioral elements they had in common. For Wheaton, Fingerman, and Boycan (1978), the 266 objectives were clustered into 16 types of engagements. This research represents a valuable resource, but for two reasons the work could not simply be extended to include M1 gunnery. First, Wheaton, et al. (1978) confined their analysis to tank "marksmanship" and therefore excluded tactical context requirements. Second, because of significant equipment differences between the M60 and M1 tanks, seven of the sixteen M60 clusters do not apply to the M1. Four more clusters do not apply because of the elimination of HEP and BEEHIVE ammunition from the basic ammunition load.

Gunnery Domain. Our resulting definition of the tactical gunnery domain is described by two lists: (a) a list of tank gunnery behaviors, and (b) a list of tank gunnery conditions. These two lists are not independent, but contain intentional redundancies. That is, where conditions create qualitatively different gunnery behaviors (e.g. single target versus multiple targets), the behaviors are segregated as separate activities. On the other hand, some conditions (e.g. target cover and concealment) have more subtle effects (i.e., do not lead to different behaviors) and therefore do not show up as separate activities. For example, there is little difference between descriptions of procedures for engaging moving versus stationary targets. However, there are motor differences that make the condition important to recognize in training and testing. The following sections describe the two components of the gunnery domain in detail.

Tactical Gunnery Conditions

As noted above there are conditions that are inherent in the delineation of the primary functions of gunnery and there are other conditions with more subtle influence. Using research literature sources and in-house and ARI gunnery expertise, our approach was to brainstorm as many conditions as possible. Then as the organization of elements into activities proceeded, these conditions could be identified as those that were major influences on gunnery in that they create or alter behavior requirements and those that may affect performance in less obvious ways. For example, type of target being engaged determines weapon used and therefore creates a significant alteration in gunnery behaviors required. On the other hand, terrain vegetation may influence how well targets can be detected, but does not otherwise change the behavior requirements for searching.

The results of our brainstorming of tactical gunnery conditions are described in Table 2-3. Twenty-two different environmental parameters are identified along with the conditions defining each parameter. They were compiled from a variety of sources including FM 17-12-1 (1986) and Kraemer (1983) for M1 specific guidelines. In addition, M60-series tank engagement conditions as described by Kraemer, Boldovici, and Boycan (1975); Melching, Campbell, and Hoffman (1982); and Wheaton, Fingerman, and Boycan (1978) were also reviewed. Finally, platoon tactics doctrine, as described in FC 17-15 (Division 86 Tank Platoon), was reviewed to insure inclusion of platoon level context.

Referring to Table 2-3, Parameters 1 through 9 are threat parameters. Together with Parameter 10 (NBC Conditions), they are sufficient to describe most threat situations that may be confronted. Parameters 11, 12, and 13 give own vehicle, personnel, and supplies status. Parameters 14 through 18 describe mission requirements. In addition to distinguishing between offense and defense, these parameters introduce conditions related to fire distribution and control, and movement and coordination among tanks in a section or in a platoon. These are graded aspects of "tactical proficiency" in Gunnery Tables IX through XII where points are awarded for fire commands, fire distribution and control, tactical movement, and tactical reporting. Specific techniques (e.g. frontal versus cross fire) are described in FM 17-12-1 and FC 17-15. Parameter 17 (Special Engagement Techniques) includes the condition that contact is to be avoided (by-pass). Finally, parameters 19 through 22 describe environmental conditions that affect gunnery outcomes.

Again, many of these conditions determine appropriate behavior and are apparent in the organization of gunnery activities below, while others may have more subtle effects including difficulty of the activities (e.g. zig-zag moving versus stationary targets) and influence on crews' affective and motivational dispositions underlying their gunnery performance (e.g., low ammunition supplies). This second type of condition does not require crews to substantially change the behaviors as laid out in the activities analysis. Rather, they represent conditions that make the activities more difficult or distractions that can disrupt that behavior and, conse-quently, reduce performance. For example, target concealment and NBC conditions can increase performance difficulty and perceived threat, but do not create qualitatively different performance requirements. For convenience in later discussion, we will refer to the those conditions that are directly incorporated into the organization of gunnery activities as primary conditions, and those effects that are not so obvious as secondary conditions. The comments in Table 2-3 identify the conditions as primary or secondary.

FM 17-12-1 defines five "basic factors" of gunnery. These include (1) firing tank motion, (2) target motion and number of targets, (3) visibility, (4) sight used, primary or auxiliary, and (5) engagement technique, battlesight or precision. Only one of these, visibility, is included as such in our analysis. Firing tank motion is incorporated in parameters 14 (Mission) and 17 (Special engagement techniques). The

Table 2-3

M1 Tactical Gunnery Conditions

Parameters	Conditions	Comments
1. Target type	Main Gun a. Tank b. Personnel carrier c. Helicopter d. Bunker Machinegun e. Antitank f. Truck g. Troops (including antitank grenade launchers and antitank grenade missile teams) h. Fixed wing, high performance aircraft	Distinction between main gun and machinegun targets is primary. Within main and machinegun conditions, targets are secondary.
2. Target movement	Stationary a. Front b. Flank c. Oblique Moving d. Flank e. Oblique f. Zig-zag g. Approaching h. Retreating	Stationary versus moving is primary in that it affects the need to track; otherwise the conditions are secondary.
3. Target cover/ concealment	a. Fully exposed b. Hull defilade c. Turret defilade d. Fully hidden	Secondary conditions
4. Target array	a. Single targets in distinctly separate engagements b. Multiple targets in distinctly separate engagements c. Continuous, unpredictably appearing targets such that some appear individually and some appear with others	Primary conditions

(table continues)

Parameters	Conditions	Comments
5. Target orientation	a. Threat weapons oriented on own tank b. Threat weapons oriented elsewhere	Secondary conditions (affects how targets are classified, but doesn't change activities)
6. Target range	a. Up to 900 (Coax tracer burn-out) b. 900-1800 (Cal .50 maximum effective range) c. 1800 and over	These range intervals (along with target type) are primary conditions for weapon selection. Additional intervals within each category are secondary conditions for range estimation and evaluation of laser returns. Additional range intervals, base on the error tolerance of the ballistics system (e.g. +/-200 meters) should be considered part of the gunnery domain.
7. Target sector	a. Forward b. Flanks c. Rear	Secondary conditions
8. IFFN (identify friend or foe nomenclature)	a. All threat b. All friendly c. Mix	Primary conditions
9. Enemy activity	a. No contact b. Direct fire c. Indirect fire d. Obstacles e. Minefields f. Electronic countermeasures	Secondary conditions
10. NBC (nuclear, biological, chemical) conditions	a. Free of hazards b. MOPP Level 1 c. MOPP Level 2 d. MOPP Level 3 e. MOPP Level 4	Secondary conditions

(table continues)

Parameters	Conditions	Comments
11. Equipment status	a. Fully operational b. GPS failure c. Lead angle failure d. TIS failure (night) e. Crosswind sensor failure f. Cant sensor failure g. Loss of symbology h. Stabilization failure i. LRF failure j. Turret power failure k. Computer failure	Secondary conditions
12. Number of crewman	a. Four b. Three	Primary conditions
13. Supply shortages	a. Ammo b. Fuel c. Food d. Smoke grenades e. Other f. None	Primary with respect to ammon selection, otherwise conditions are secondary.
14. Mission	a. Moving offense b. Stationary defense	Primary conditions
15. Fire control	a. Single tank Section Control b. Frontal c. Cross d. Depth Platoon Control e. Frontal f. Cross g. Depth	Secondary conditions (affects target selection)
16. Formation	a. Column b. Echelon left/right c. Staggered column d. Line e. Wedge f. Herringbone g. Vee h. Coil i. Combat column	Secondary conditions

(table continues)

Parameters	Conditions	Comments
17. Special engagement requirements	a. Surprise targets b. Assault fire c. Support by fire d. Fire and maneuver e. By-pass	Secondary conditions
18. Space	Offensive a. Support by fire position interval b. Fire and maneuver interval c. Assault interval Defense d. Fire position interval	Secondary conditions
19. Visibility	Day a. Unlimited b. Haze, smoke, rain, snow or fog Night c. Without illumination d. With continuous illumination (e.g., fires, moon) e. With periodic illumination (e.g., flares)	Primary with respect to selection of TIS and LRF
20. Terrain grade	a. Level b. Up slope c. Down slope d. Hilly	Secondary conditions
21. Terrain vegetation	a. None b. Brush c. Trees - scattered d. Trees - dense woods	Secondary conditions
22. Cultural features	a. Rural b. Villages/towns c. Suburban d. Urban	Secondary conditions

moving/stationary distinction fits well with practical considerations for training (e.g. exercise design and selection of tank ranges). However one does not enter a battle with the decision to fire from a stationary versus moving tank, but rather with a mission. The mission is the primary determinant of own vehicle motion: moving primarily for offensive missions and stationary primarily for defensive mission. Moving to a short halt, a variation of moving, may be used depending on equipment status or other conditions. Similarly, sight used and engagement technique are not conditions themselves, but are reactions to conditions. That is, sight used is primarily a function of equipment operational status and visibility. These appear as parameters 11 and 19. Likewise, engagement technique is a function of other parameters including target range, type, ammunition loaded at the time of contact, and equipment status. Therefore, sight and engagement technique were not directly adopted as gunnery parameters. Rather, the conditions that determine sight and engagement technique were included. Our operating principle was to identify as parameters only those factors that affect gunnery and are not under the immediate control of the M1 crew. Finally, target motion and number of targets are presented separately as parameter 2 (target movement) and parameter 3 (target array). A time factor is added to target array because number of targets also implies some time interval associated with their appearance.

Of the eleven conditions identified by Kraemer et al. (1975), five were not used in our analysis. These include (1) crewman firing, (2) weapon used, (3) firing mode, (4) fire control instrument, and (5) ammunition. Given that tactical context perspective, these factors do not represent environmental conditions, but are the products of crew decisions in relation to the environment. For example, use of SABOT versus HEAT ammunition depends largely on the type of target to be engaged, and secondarily on ammunition supplies. Target type and supply levels, but not ammunition being fired, are represented in our conditions.

Tactical Gunnery Behaviors

Analysis of gunnery behaviors occurred at two levels. The higher level units of behaviors are referred to as "activities" and are roughly equivalent to the term "task." The former term was adopted to distinguish between the outcome of the present analysis and the official list of armor tasks that has been formally approved by the Army. The subordinate units of analysis are called "performance elements" or simply "elements" which may be equated to steps within a task. These two levels of analysis are detailed in the following sections.

Activities. Table 2-4 presents the activities included in our definition of the M1 tank gunnery domain. For the most part, activities were derived from accepted armor doctrine. For instance, Activities 3 through 10 correspond to chapters and sections within chapters of FM 17-12-1. Activities 1 and 2 are TM activities in preparation for firing. Activity 11 (Assess Results of Engagement) relates tactical

Table 2-4

M1 Tactical Gunnery Activities

Activities, Parts, and Options to Gunnery Behaviors

ACTIVITY 1. PREPARE STATIONS FOR OPERATION (PREOPS)

ACTIVITY 2. PERFORM PREPARE-TO-FIRE (PRE-FIRE) CHECKS
- Option 2.1. Prepare for Offense
- Option 2.2. Prepare for Defense

ACTIVITY 3. ACQUIRE TARGET(S)
- Part 3.1. Search for Target(s)
  - Option 3.1.1. Search Open Hatch--Day
  - Option 3.1.2. Search Closed Hatch--Day
  - Option 3.1.2. Search at Night
- Part 3.2. Detect/Locate/Identify Target(s)
- Part 3.3. Evaluate Situation

ACTIVITY 4. ENGAGE SINGLE TARGET WITH THE MAIN GUN
- Option 4.1. Engage single target from the offense using precision gunnery
- Option 4.2. Engage single target from the defense using precision gunnery
- Option 4.3. Gunner cannot identify announced target
- Option 4.4. Engage targets using TIS

ACTIVITY 5. ADJUST FIRE
- Option 5.1. Use reengage technique
- Option 5.2. Use standard adjustment
- Option 5.3. Use TC adjustment

ACTIVITY 6. ENGAGE A SINGLE TARGET WITH THE COAX

ACTIVITY 7. ENGAGE MULTIPLE TARGETS WITH THE MAIN GUN

ACTIVITY 8. ENGAGE TARGETS WITH THE CAL .50 (INCLUDING SIMULTANEOUS ENGAGEMENTS)
- Option 8.1. Simultaneous targets
- Option 8.2. Cal .50 targets

ACTIVITY 9. ENGAGE TARGET USING DEGRADED GUNNERY TECHNIQUES
- Option 9.1. Engage target using battlesight gunnery
- Option 9.2. Engage target given ineffective LRF
- Option 9.3. Engage target given multiple returns from LRF
- Option 9.4. Engage target given no range display (loss of symbology)
- Option 9.5. Engage target given crosswind sensor failure
- Option 9.6. Engage target given cant sensor failure
- Option 9.7. Engage target given lead angle sensor failure
- Option 9.8. Engage target given GPS failure (day channel)

(table continues)

Activities, Parts, and Options to Gunnery Behaviors

Option 9.9. Engage target given GPS/TIS failure
Option 9.10. Engage target using GAS
Option 9.11. Engage target given stabilization system failure (in emergency mode)
Option 9.12. Engage target given turret power failure (in manual mode)

ACTIVITY 10. ENGAGE TARGET(S) FROM THE TC POSITION

ACTIVITY 11. ASSESS RESULTS OF ENGAGEMENT

considerations discussed in FC 17-15. Many of the activities are further subdivided into "parts" and "options." Parts are used in the Target Acquisition activity to divide otherwise sequential elements. Options are used in several activities to indicate alternative courses of actions that are dependent on various equipment conditions.

M1 gunnery may be characterized as procedural to the extent that, for any given set of conditions, fairly precise steps can be laid out for executing an engagement. However, there are an enormous number of combinations of conditions possible. All of the combinations of conditions on the above list may not be realistic, so it would be very difficult to get an exact count on the number of possible combinations. However, a very rough estimate of the possible combinations of conditions is nearly 10 billion.[1] Obviously, the differences among these combinations will vary from trivial to significant. The divisions of activities in the gunnery domain reflects differences in conditions which are sufficient to alter the basic procedure by more than just a few steps. The parameters that determine which activities and which options within activities are followed are the primary conditions as labeled in Table 2-3. For example, target array (parameter 4) is a primary conditions because it determines whether an engagement is for a single target, multiple targets, or simultaneous targets (activities 4, 7 and 8, respectively). The effects of the remaining, secondary conditions are more subtle and are not apparent in the divisions of the activities. For example, parameter 5 is target cover and concealment. Although these may affect the difficulty of detecting, identifying, and hitting targets, the behaviors executed are not altered.

The activities are not purely sequential, but branch and loop as indicated in Figure 2-1. The branching connotes decisions made by the TC based on what kind and how many targets are detected and other mission conditions. Pre-operations checks and prefire checks should precede all tactical missions. These checks include evaluations of equipment, mission, and environment. During these checks, equipment malfunctions may be discovered. If malfunctions are not correctable, degraded mode techniques may be called for in continued execution of the mission. Figure 2-1 depicts degraded mode techniques as a box between pre-fire checks and target acquisition. These degraded mode techniques are most easily described as alterations in procedures rather than as different procedures. Thus, the question mark in the box and the placement of the box in Figure 2-1 should be interpreted to mean that various alterations in task procedures throughout the remainder of the mission should be

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[1]This was calculated as the product of the following conditions per parameter: Target type - 8; Target movement - 5; Target cover - 4; Target array - 3; target orientation - 2; Target range - 3; Target sector - 3; IFFN - 3; Enemy activity - 6; NBC - 2; Equipment status - 11; Number of crewman - 2; Supply shortages - 5; Mission and formation - 8; Special engagement techniques - 3; Visibility - 4; Terrain grade - 4; Terrain vegetation - 3. Some parameters were omitted and some combined to avoid redundancy.

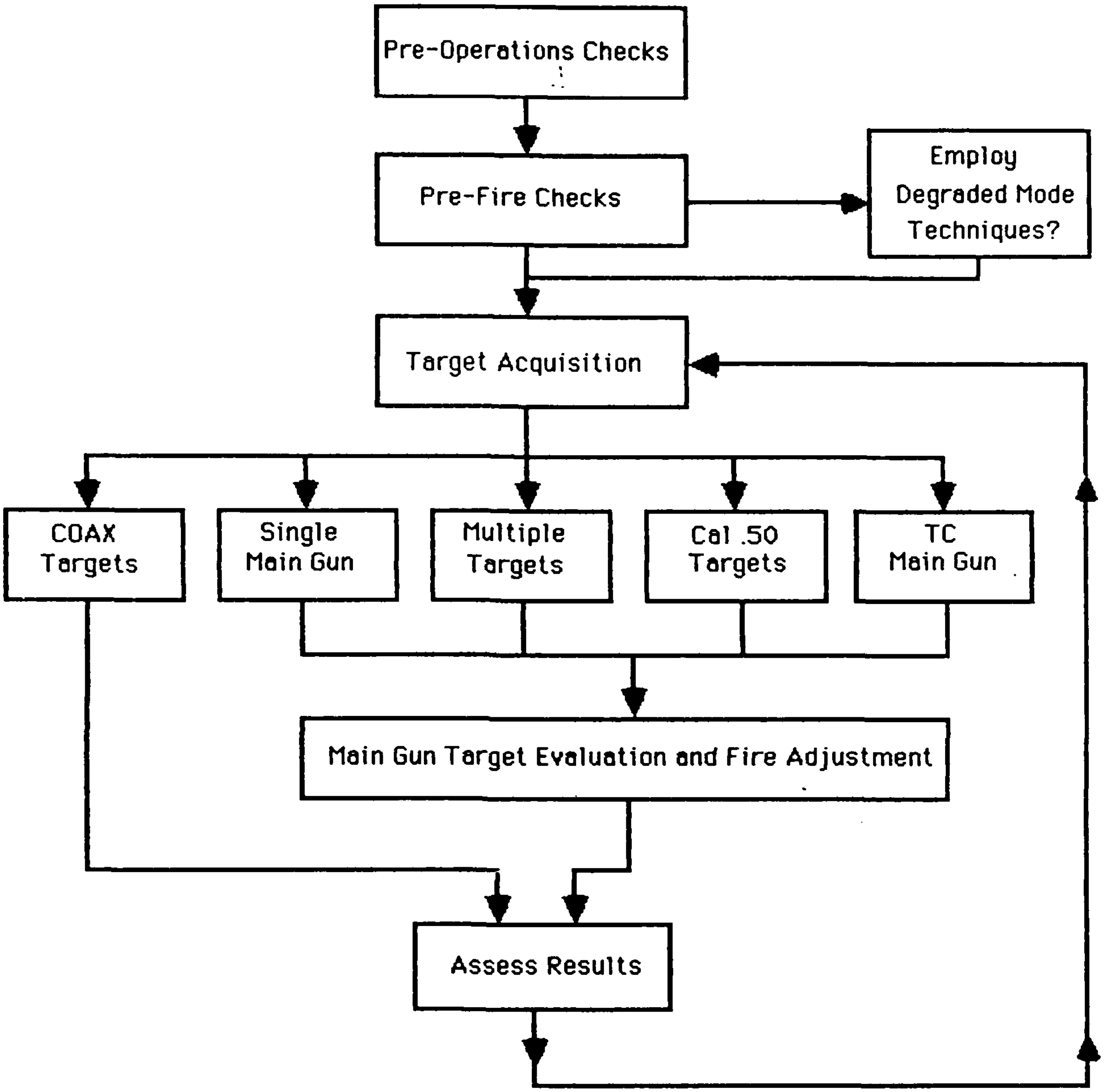

Figure 2-1. Optional sequences for performing tactical gunnery.

employed if equipment malfunctions occur. Activity 9 in Table 2-4 lists 12 possible degraded mode options.

Target acquisition (Activity 3) precedes all engagements. Subsequent to acquisition are five types of engagements that are sufficiently different in their procedural requirements to be designated as separate activities. These include single target main gun engagements (Activity 4), coax engagements (Activity 6), multiple target engagements (Activity 7), caliber .50 target engagements (Activity 8), and engagements from the TC position (Activity 10). With the fire control system of the M1, there is not sufficient difference in behavior requirements to distinguish between moving and stationary targets. In contrast, movement of the firing tank is noted within Activity 4 (Engage Single Target with the Main Gun) as two separate activities (Options 4.1 and 4.2). To avoid redundancy, this distinction is not repeated within the other firing activities, although it should be understood that these options are available and should be practiced.

Activity 5 (Adjust Fire) is sequenced after the four main gun engagement activities. We have combined target evaluation and fire adjustment because they are closely associated elements and to avoid redundancy across the main gun engagement techniques, each of which leads to evaluation of target hit and possible fire adjustment. The final tactical gunnery activity is Assess Results, which is viewed as a transition activity. In Figure 2-1 it is assumed the mission continues and the tank crews pick back up with target acquisition. Alternatively the mission may end with this activity.

Performance Elements. The detailing of performance elements within the activities was conducted concomitantly with the specification of activities. Recall we argued that, given a set of conditions, tactical gunnery could be reduced to a sequential, albeit lengthy, procedure. However, there are numerous conditions that create variations in the procedures. One of the reasons for creating separate activities was to accommodate the significant differences in procedural elements necessitated by these varying conditional parameters. That necessitated the examination of elements prior to settling on the specification of activities. For example, some activity divisions were created (e.g., firing from a moving versus stationary tank) while other were not (e.g., firing at stationary versus moving targets) based on the similarity of procedures necessary under these different conditions. Similarly, the exact placement of boundaries between activities resulted from joint considerations of the major goal of each activity and the commonalities between elements near potential boundaries between activities. For example, the TC's decision to engage a target, and his selection of weapon and crewman were placed in Activity 3 (Acquire Targets) to allow for the branching that must occur as a result of these decisions. Similarly, while "recovering sight picture" is the behavior that immediately follows firing, it is most logically associated with the goal of evaluating target hit and was placed in Activity 5 (Adjust Fire). Thus, in the initial stages of analysis, partitioning the gunnery domain into activities,

parts, and options and detailing the elements within these divisions were iterative, interacting processes.

Defining the tactical gunnery domain in broad terms necessitated the use of a variety of sources of information. The two most important sources were FC 17-12-1 and TM 9-2350-255-10. Kraemer's (1983) M1 Crew Drills provided another source of information. Two additional sources provided somewhat non-traditional elements for gunnery: (a) A research report by Drucker, Hannaman, Melching, and O'Brien (1983) describes non-procedural, decision-making elements in gunnery; and (b) FC 17-15 (Division 86 Tank Platoon) was consulted to identify behaviors that may not be strictly related to "putting steel on target," but are important for platoon coordination and occur simultaneously with behaviors more directly related to marksmanship. These coordination behaviors can create disruptive time-sharing problems unless they are incorporated into gunnery practice. While neither type of behavior may be difficult by itself, smooth integration occurs only with practice. In order to keep track of these integration requirements, they were explicitly included among the behaviors of the tactical gunnery domain.

To avoid excess redundancy, two rules were adopted. First, procedures that are normally conducted using the TM (e.g. boresight) were not laid out in detail; rather, the TM was referenced. Second, cross-referencing between activities was used. The first rule applied to Activities 1 and 2; the second rule affected activities 7 through 10. Regardless of such formatting short-cuts, each activity still represents an internally consistent objective.

The final tactical gunnery task analysis is presented in Volume II, Appendix A. The basic format of presenting the simultaneous behaviors for each of the tank crewman in four columns follows the convention of Kraemer (1983) and FM 17-12-1. However, the analysis is more inclusive than either source in both depth and breadth: (a) in depth because greater detail is provided in describing behavior, and (b) in breadth because elements associated with activities beyond pure gunnery are included.

CHAPTER 3

ARMOR PERFORMANCE DEFICIENCIES

The purpose of the research described in the present chapter was to identify known armor performance deficiencies upon which we would focus the device-based training program. In training development, performance deficiencies are commonly identified through structured interviews of and ratings by subject matter experts (SMEs). Having conducted many similar analyses, project staff members were wary of this source of information because of its inherent subjectivity and unreliability. Indeed, we initially compiled a rating form of gunnery skills and knowledges for experts to estimate (a) the percentage of crews deficient in gunnery skill and/or knowledge component, and (b) the importance of the components to overall gunnery performance. Results from a pilot study using two experts indicated that they produced highly variable estimates of percent crews deficient and tended to rate every component as equally important. The other problem with generating our own survey data is that there are no M1 TO&E units at Fort Knox. Therefore, there is a local shortage of experts who are familiar with performance deficiencies of experienced armor crewmen.

We subsequently pursued the issue of task performance deficiencies using three other information sources that were thought to yield more objective data. First, we examined survey data collected by the Directorate of Evaluation and Standardization (DOES). Second, we conducted a review of the tank gunnery literature. Third, we analyzed Table VIII performance data from Grafenwöhr. The findings from these data sources are summarized below.

DOES Survey Data

One additional reason for not generating our own survey data is that the DOES maintains related data for their own purposes. They periodically survey field personnel to ascertain the quality of training performed by the Armor School. Although the focus of these surveys is on recent Armor School graduates rather than experienced crewmen, the results should nevertheless provide some indication of the relative difficulty of gunnery tasks.

No one course is directly responsible for training tank gunnery. Tank commander skills are taught in the Basic Noncommissioned Officer Course (BNCOC); however, no BNCOC data were available. Driver and loader skills are emphasized in entry-level or One Station Unit Training (OSUT) with gunnery skills classified as "familiarization" training. That means that OSUT graduates are not expected to be proficient gunners. Gunners' skills are learned on-the-job through assignment rotation and unit training. Therefore, no one course represents the population we are most interested in regarding the difficulty of gunnery tasks. OSUT does, however, offer a view of the difficulty of driver and loader tasks, and

DOES survey data were available for OSUT. Performance of gunner tasks is estimated by the survey, but because recent OSUT graduates are not usually assigned to gunner positions, the results must be interpreted cautiously.

Supervisors (n = 23) rated recent OSUT graduates' performance level (cannot perform, less than adequate, adequate, more than adequate, and exception) and performance frequency (never performed, seldom performed, performed monthly, performed weekly, performed daily) for Skill Level One Soldiers' Manual Tasks. Task means for these two ratings were highly correlated ($\underline{r}$ = .69, $\underline{p}$<.01) suggesting that, at least from the observations of the raters, task proficiency is dependent on frequency. Examination of the frequency-by-performance plot suggested a curvilinear trend. That is, the incremental effects of task frequency on performance are greatest at the low end of frequency and plateau as frequency increases. This was tested by adding a curvilinear component (frequency squared) to a multiple regression model used to predict performance ratings from frequency ratings. The curvilinear component was significant ($\underline{p}$<.05), increasing the prediction of performance to R=.72, $\underline{p}$<.01). Figure 3-1 depicted the relationship between frequency and performance. Each cross represents a task and the curved line is the regression function.

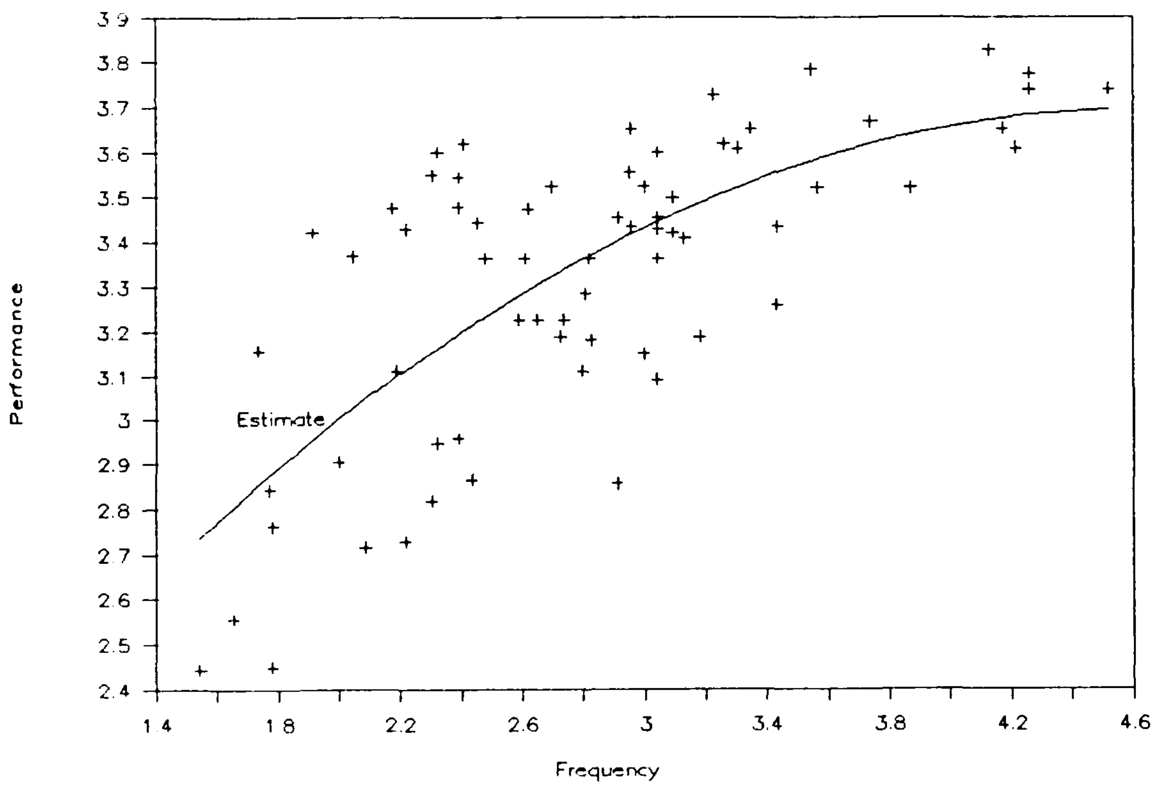

Figure 3-1. Performance level as a function of performance frequency for 68 armor tasks.

Because of their strong relationship with task frequency ratings, performance ratings alone are not a good indicator of task difficulty. That is, tasks may have low performance ratings because they are infrequently practiced. Tasks that are frequently performed and also have low performance ratings would be of more interest. In order to obtain a task difficulty index independent of frequency, residual performance was calculated as the difference between performance level that would be predicted by the regression function and actual performance level. Residual scores near zero indicate tasks with performance levels very close to what is expected based on frequency of performance. Residual scores greater than zero indicate tasks with performance levels higher than expected ("easy" tasks). Residual scores less than zero indicate tasks with performance lower than expected or "hard" tasks. Task means for frequency, performance and residual performance are presented in Appendix B.

Of the 68 tasks addressed in the surveys, 18 tasks fell into our domain of gunnery. Only three of these tasks were in the lower third of the distribution of residual performance.[2] That is, three gunnery related tasks were performed less well than would be predicted by the amount of practice they received. These tasks included, beginning with the most difficult: (a) identify threat aircraft, (b) identify friendly and threat armored vehicles, and (c) drive an M1 tank. The two identification tasks are both below the median in task frequency and also in raw performance. On the other hand, driving is one of the highest frequency tasks (7th out of 68). However, in terms of performance, it ranks 23rd.

On the other end of the spectrum, 12 of the 18 tasks fell in the upper third (easy) portion of the residual performance distribution, with performance better than expected. Among the 9 "least difficult" of the 68 tasks were the following gunnery related tasks: (a) engage with the COAX, (b) engage with the main gun, (c) zero the COAX, and (d) engage with loader's M240. While each of these tasks fell at or below the median on performance, the level is commensurate with frequency of performance.

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[2]It is, of course, possible that the residual scores represent only random variance, and that their rank ordering is meaningless. Because the residual scores are mean scores, it is possible to estimate what their variance should be (by chance) from the variance of the individual level scores from which they were derived. To do this, an individual level estimate of residual variance was obtained by a general linear regression model predicting performance ratings from task designations (67 coded vectors) and individual frequency rating data (frequency and frequency squared) across the 1564 (63 tasks x 23 persons) performance ratings. Mean square error was .824, which divided by 67 degrees of freedom for tasks, gives an estimated standard error of the mean of .012. Observed variance of the mean residual was .055. The ratio of these variances (4.58) with 67 and 1358 degrees of freedom is statistically significant $p<.01$, indicating real differences among the residual means. Interpreting the extreme thirds of the distribution is therefore reasonable.

This finding suggests that there are not likely to be an unusual training problems associated with these tasks.

These data are interesting both for what they suggest are difficult tasks and what they suggest are not difficult tasks. Aircraft and vehicle identification are well known as difficult tasks (e.g., Warnick & Kubala, 1979; Knerr et al., 1986). In addition to their difficultly, they are relatively infrequently practiced tasks (less than monthly). Certainly there would be some advantage to integrating target identification into other type of practice, most obviously gunnery exercises. For driving, there may be a difference in the kind of driving most frequently done (e.g. to and from the motor pool) and the tactical driving needed for quality performance.

The gunnery engagement skills were not singled out as deficient by our residual performance method. Rather they were described as on par with frequency. In other words, there were no deficiencies in gunnery performance that were not also associated with infrequent in practice. Thus, the issue for training is not the difficulty of the tasks but the opportunity to practice. The Skill Level One Soldiers, on whom the ratings were focused, may be expected to improve their gunnery skills with additional practice.

Empirical Research Literature

Unlike most other job domains, there is considerable empirical research on armor gunnery performance. To review this extensive literature, the domain of gunnery was broken down into a number of broad, generally recognized categories of armor skills and knowledges. In that regard, the literature on armor job samples[3] was examined particularly closely since many armor job samples are addressed specifically to these gunnery skills and knowledges components. Unfortunately, the literature has not directly addressed the issue of identifying performance deficiencies. Nevertheless, some findings have addressed issues that are related to task criticality. The following questions are basic to the issues at hand:

1. Is there evidence for any relationship between the skill or knowledge component and gunnery performance? Positive correlations may be interpreted as evidence that a particular component is critical. The major problem in answering this question is the criterion of gunnery performance. In most of the literature surveyed, the criterion was performance on a gunnery range; in fewer cases, other criteria (e.g., performance in training) was used. Gunnery performance was chosen most

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[3]Job sample tests are abstracted portions of a particular job on which performance may be scored. Job sample test scores are usually used to predict performance on the job for purposes of personnel selection and classification, although Kress (1981) used the principle of job sampling to design a training program for armor crewmen.

often, because it is the most obvious and face valid criterion for gunnery proficiency. Unfortunately, gunnery performance is notoriously unreliable (e.g., Powers, McCluskey, Haggard, Boycan, & Steinheiser, 1975). Gunnery may be more reliably measured by high fidelity simulators (e.g., Graham 1986), however research in this area has only recently begun to examine these and related issues.

2. Is the skill or knowledge component trainable? In most cases, the available research findings were correlational in nature. Consequently, we cannot determine whether the relationships between skill/knowledge and gunnery performance are due to differences in achievement or aptitude. Because our interest is in training gunnery skills, the focus of the present review is on those skills that are accumulated as a result of experience rather than those that distinguish innately good and bad performers. Skill and knowledge are generally regarded as trainable if performance on the components can be shown to increase with practice or with relevant experience. We may also ask whether or not the acquired skills transfer from the training situation to the operational context. Unfortunately, the literature has not addressed this issue well. (For a methodological critique, see Boldovici, in press.)

The details of the literature review are provided in Appendix C, and the findings are summarized in Table 3-1. A table entry of "yes" indicates that there is good evidence for an affirmative answer to one or the other research question. "Maybe" denotes that the findings from the research literature are mixed, but at least one study indicates that the component is correlated with some aspect of gunnery proficiency. "No research" simply indicates that no empirical research has not been addressed to the research question. With regard to the final entry, "no evidence," it is important to note that we cannot conclude from a lack of positive findings that an effect does not exist.[4] For instance, it would be wrong to conclude that the knowledge and skill components related to adjustment of fire are not significant. Two objections may be raised against such a conclusion. First of all, as stated earlier, the criterion for gunnery proficiency (performance on Table VIII) may have been unreliably measured, effectively preventing any score to correlate with gunnery. Second, performance on the skill and knowledge component may have been invalidly or unreliably measured.

We could confirm only one component of gunnery (observational skill) that correlated with gunnery performance. In another context, a similar lack of findings was reported by Means and Gott (1986) who found no differences between more- and less-expert Air Force troubleshooters in basic electronics knowledge when tested in isolation. However, they found important deficiencies in basic knowledges when the technicians performed actual complex troubleshooting tasks. Apparently, the isolated knowledges were somehow different from the knowledges in the job context. The

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[4]In the practice of statistical analysis, this error in reasoning is referred to as "accepting the null hypothesis."

Table 3-1

Findings from the Empirical Literature

Hypothesized Component	Research Questions: Related to Gunnery Proficiency?	Research Questions: Trainable?
Target Acquisition		
Crew Search	No research	No research
Detection	Maybe	Yes
Location	No research	No research
Identification	Maybe	Yes
Classification	No evidence	No evidence
Range Estimation	No evidence	No evidence
Knowledge of Fire Control System	No research	Maybe
Firing the First Round		
Sight Picture/	No evidence	No research
Stationary Engagements	Maybe	Yes
Tracking/	Maybe	Yes
Moving Engagements	Maybe	Maybe
Firing Subsequent Rounds		
Observations	Yes	No research
Fire Adjustments	No evidence	No research
Procedural Skills and Knowledges		
Technical Manual	No evidence	No research
Fire Control Computer	Maybe	No research

authors concluded that if troubleshooting is the targeted skill, it should be studied directly, rather than by examining tests that correlate with troubleshooting performance. Their conclusions suggested that we need to examine other data sources that measure gunnery performance per se. One such source is the Grafenwöhr gunnery data base that is maintained by the Office, Chief of Armor (OCOA). This data base provides much information on the performance of armor crews on Table VIII.

Grafenwöhr Gunnery Data Base

Table VIII is a live-fire gunnery test designed to determine whether or not individual crews are qualified. The Office, Chief of Armor (OCOA) maintains a detailed data base on Table VIII performance at Grafenwöhr, one of several sites at which Table VIII is administered. The data base provides information for the Chief of the Armor Branch and serves as a source of research data for other Army organizations. The data base is a rich and complex source of information on gunnery performance, including information about the crewmembers, the targets, and the test conditions. In many ways, this data base provides an ideal source on information about gunnery performance deficiencies.

Grafenwöhr Table VIII data from January - July 1986 were manipulated to answer a list of specific questions about gunnery performance. Details of the analysis and the findings are presented in Appendix D. The results did not reveal many specific performance deficiencies that could be addressed by the proposed device-based training/testing program. Nevertheless, the analysis did provide some findings that may be of interest to the armor community. These findings may be summarized as follows:

1. The data failed to confirm expected differences between moving vs. stationary targets, offensive vs. defensive engagements, and precision vs. battlesight engagements.

2. Performance was slower and less accurate for distant and/or small targets, but this relationship is probably due to both human and machine error.

3. Gunnery performance was dramatically reduced when crews engaged targets in an NBC environment.

4. Crew cuts associated with the fire commands were the most likely observed procedural errors. Furthermore, errors in fire commands were associated with poorer gunnery performance, although few of the comparisons were statistically reliable.

5. Similar differences between engagements that were observed in the Grafenwöhr data base were also observed in findings from other Table VIII sites, supporting the generality of the findings.

Conclusions

These various data sources did not allow us to identify a definitive set of performance deficiencies. As a result of these negative results, we are left with two plausible interpretations that cannot be confirmed or denied by the data alone. One interpretation is that our methods were not sensitive enough to detect performance differences between components of armor gunnery. The subjective weight of the evidence across three different sources of information would tend to deny this interpretation. Furthermore, it offers no implication for the design of our training program.

The second interpretation that may be derived from these results is that there are actually no outstanding differences between components in performance difficulty or criticality. Given the pilot SMEs subjective judgments that everything was important, one implication from this conclusion is that every component of gunnery is critical for training. In a sense, this must be true given the highly technical nature of armor gunnery. With the exception of very few generic skills such as ability to read technical manuals, an armor recruit enters training possessing none of the skills and knowledges related to gunnery. Furthermore, in order to perform gunnery, particularly tactical gunnery as we have defined it, he must acquire the entire domain to perform successfully. Thus, every component is critical for training. The latter is the conclusion we reached for gunnery. Consequently, the proposed device-based training program shall consider the entire domain of tactical gunnery rather than any subset of that domain.

CHAPTER 4

INSTRUCTIONAL ANALYSIS AND PERFORMANCE MEASUREMENT APPROACHES TO M1 TACTICAL GUNNERY

In Chapter 2, the performance domain of M1 tactical gunnery was presented as a series of interrelated activities. In the training context, these activities represent the initial partitioning of our terminal training objective, tactical gunnery, into subordinate objectives. The purpose of this chapter is to elaborate on our conceptual organization of these behaviors. The chapter is divided into two sections: The first describes the hierarchical analytic approach used to identify training and testing objectives; the second outlines our performance measurement approach for assessing performance within the training context. The hierarchies presented in this chapter partition all activities in the performance domain into training objectives and indicate sequences of instruction. They also identify any prerequisite objectives. The hierarchies thus represent rudimentary training plans. As such, they provide the starting point for the device evaluations leading to the recommendations for device use in gunnery training and testing.

Hierarchical Analysis Approach

A learning hierarchy is a two-dimensional representation of the super- and subordinate relationships between training objectives. As originally defined by Gagné (1962), a subordinate relationship indicates that a training objective is prerequisite to another objective. That is, in order for a student to perform at a particular skill level, he must possess all subordinate skills specified by the hierarchy. White (1973) reviewed the evidence in favor of hierarchical ordering and found that a majority of students demonstrate the skills in the predicted order. However, there were also significant numbers of students who possessed the higher level skills without possessing all subordinate skills as specified by the hierarchy. Cotton, Gallagher, and Marshall (1977) noted that one possible reason for failing to find strict hierarchical ordering is that some types of tasks are not amenable to hierarchical analysis. In that view, Gagné (1968) distinguished between intellectual skills (i.e., tasks that are procedural in nature) and verbalized knowledge (i.e., tasks requiring the recall of information or facts) with hierarchical analysis techniques applying to the former and not the latter. Nevertheless, Cotton et al. concluded that some subordinate skills "...may simply transfer to the next higher item rather than being fully prerequisite to it" (p. 189). This assumption appears to be tacitly accepted in the more recent hierarchical analysis techniques described by Resnick (1976). She distinguished between skills "...that are thought to be either necessary to performance (i.e., prerequisite to) or helpful in learning (i.e., propadeutic to) the main task" (p. 66). Thus, it appears reasonable to redefine hierarchically subordinate skills as either prerequisite or propadeutic to the immediately superior skill in the hierarchy.

Research on learning hierarchies has been criticized on grounds other than the prerequisite assumption. For instance, White (1973) found the studies of learning hierarchies to be methodologically inadequate. Others have noted the absence of an appropriate statistical model for testing hierarchical assumptions (Bergan, 1980). Possible alternative models have been suggested such as Markov models (Cotton et al., 1977), path analytic models (Bergan, 1980), and even latent class models (Bergan & Stone, 1985). Despite the criticisms of research and theoretical alternatives to learning hierarchies, no model has supplanted hierarchical analysis as a pragmatic tool for the design of training and testing. To that point, Gagné and Dick (1983) reviewed two large-scale projects--one in early mathematics education and one in military training--that employed hierarchical analysis. These authors concluded that hierarchical analytic techniques significantly contributed to the success of these projects.

Example Analysis: Introductory Mathematics

An oft-cited and highly detailed example of hierarchical analysis was provided by Resnick, Wang, and Kaplan (1973) who presented learning hierarchies for a preschool mathematics education program. An example learning hierarchy for the skills related to counting is presented in Figure 4-1. The domains of arithmetic and gunnery are similar in several respects. For one, both are governed by explicit procedural rules. Although there is a component of perceptual motor skill to gunnery performance, procedural task skills appear to predominate over fine motor skills--especially with the advent of the many automated components of the M1. Furthermore, both domains consist of a finite number of practice elements, i.e, "exercises" in math and "engagements" in gunnery. This characteristic makes task sampling relatively easy and straightforward. Because of these similarities between domains, the procedures used by Resnick et al. were examined and modified for application to the present project. The modified procedures are summarized below:

1. Hierarchies are diagrammed as inverted tree structures. Every learning objective is identified in a box and the boxes are arranged to indicate their subordinate relationships. Terminal objectives are drawn at the top of the diagram; lowest level enabling objectives are drawn at the bottom. Enabling objectives are connected to the superordinate objectives they support.

2. The analysis generally proceeds from the top down. That is, each terminal objective is analyzed to reveal subordinate objectives until a skill level is reached that may be assumed to be possessed by all members of the to-be-trained population. However, as analyses proceed downward, unexpected similarities or dissimilarities among elements may be uncovered, necessitating changes in the partitioning of upper level divisions. Thus, while the analysis generally proceeds along the vertical dimension, it is accompanied by elaboration along the horizontal dimension as well.

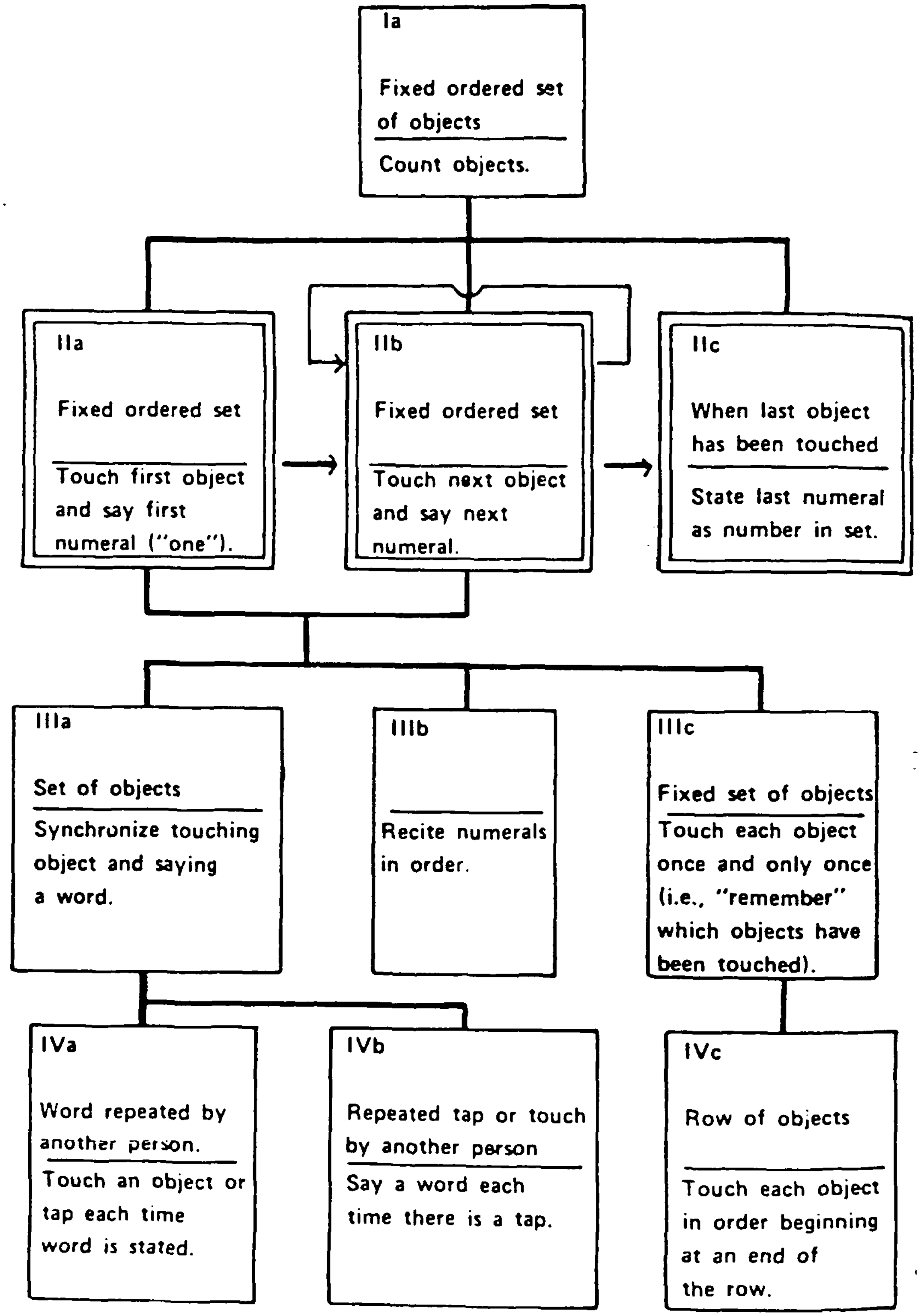

Figure 4-1. Example learning hierarchy of counting task (from Resnick, Wang, & Kaplan, 1973. Reprinted with permission).

3. The hierarchy is behaviorally based. Information in each box includes the stimulus situation (above the vertical line) and appropriate responses (below the vertical line) associated with each training and testing objective. This format is compatible with the Army's philosophy toward training and testing that promotes explicit statements of conditions and actions for each training and testing objective.

4. The hierarchy provides a formal model of performance. Resnick et al.'s method is consistent with production systems models of performance. Productions are statements consisting of an action paired with conditions under which the action is to be performed. Production systems have been used to model overt procedural performance (e.g., Sticha, 1987; Knerr et al., 1986) as well as covert mental processes (Newell 1973; Anderson, 1982). The implication is that this approach can model behavioral as well as mental processes.

5. Arrows are used to indicate sequential dependencies between overt behaviors. Loops are used to indicate that performers must recycle through certain series of steps. Decision points are represented by splitting the box vertically to indicate different stimulus-response contingencies.

6. Prerequisites skills are indicated below the level of overt behaviors. These prerequisite skills are not actually performed in the course of the terminal behavior but are assumed to facilitate learning of the higher level skill. Subordinate skills may be further analyzed into lower order components until the lowest level of skill is reached. Note, however, that even the prerequisite skills are behaviorally defined by providing a statement of specific conditions and actions that apply.

Example Analysis: Battlesight Gunnery

To illustrate how the analytic procedures described by Resnick et al. (1973) were incorporated and modified in the current project, Figure 4-2 presents an analysis of Option 9.1: Engage target using battlesight gunnery. This activity was chosen as an example, because it is somewhat simpler than most objectives in the gunnery domain thereby facilitating its exposition. Nevertheless, the example illustrates most of the features of the analysis method. The analyses for remainder of the gunnery domain are contained in Appendix E.

One of the most salient distinctions between mathematics and gunnery performance is that gunnery tasks not only require individual performances, but the collective interaction of the individuals acting as a crew. As a result, individual behavioral objectives must be clarified by using the crewman position (TC, GNR, LDR, or DVR) as the subjects of the action statements. If no subject is provided, it is understood that the entire crew performs the action. At the prerequisite level, subjects are not provided implying that all crewmen should possess these basic skills. The crewman position name does not imply that he alone should be

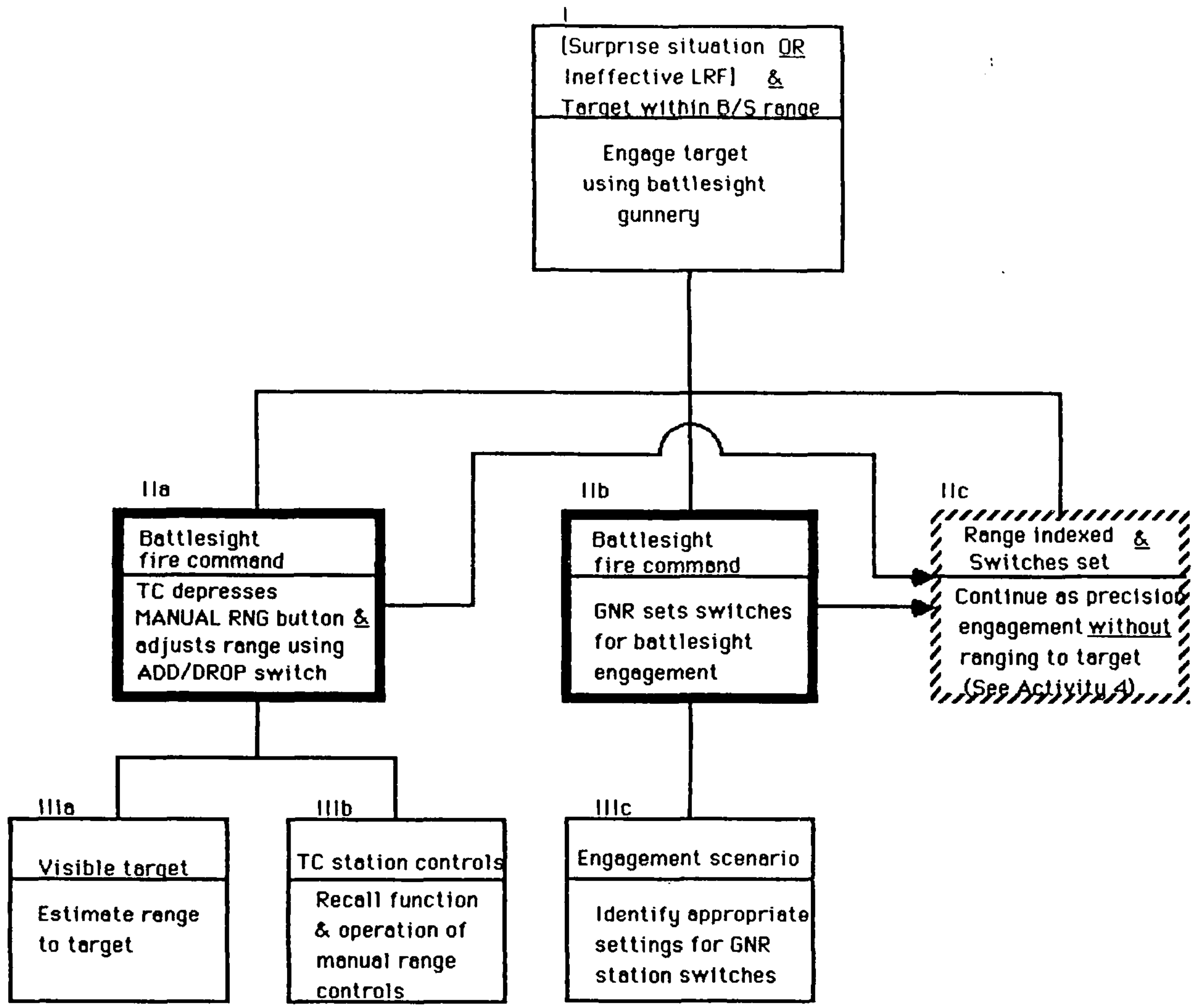

Figure 4-2. Example hierarchical skills analysis: Engage target using battlesight gunnery.

trained on the objective. On the contrary, we assume that students in the course will be cross-trained on all skills.

Level I of Figure 4-2 corresponds to the crew-level objective of engaging a target using battlesight gunnery. As illustrated in the figure, some conditions and actions were best described as combinations of simpler stimuli or responses. The logical operators "&" and "OR" were used to connect the conditions. The operators were underlined to set them off from the rest of the text within the boxes. In the present case, the Level I objective indicates that battlesight gunnery is appropriate in either a surprise situation or when the LRF is ineffective. However, the target must be within battlesight range in either case.

Level II of this figure corresponds to the behavioral component of the task. The behavioral objectives are outlined by noticeably thicker lines to distinguish them from crew-level and prerequisite objectives.[5] In the present analysis, the tank commander's fire command occurs as a result of the preceding acquisition process. Therefore the initiating condition for both Objectives IIa and IIb is the battlesight fire command. Note that the arrows indicate that the first two behavioral objectives are not performed sequentially, but rather occur simultaneously. Objective IIa calls for the TC to use the manual range controls to index battlesight range into the ballistic computer, whereas Objective IIb relates to the gunner setting the gunner panel switches for a battlesight engagement. After the first two behavioral objectives are accomplished, the analysis indicates that the soldier should continue to behave as outlined in Activity 4: Engage Target Using Precision Gunnery. The dashed lines used to enclose Objective IIc indicate that the objective has been previously analyzed in detail. This convention, which was used by Resnick et al., reduced unnecessary redundancy across analyses.

Note that Objectives IIa and IIb consist of multiple performance elements. For example, Objective IIb (the act of setting gunner switch positions) consists of the following behavioral elements: Ensure that (a) FIRE CONTROL switch is in NORMAL position, (b) LRF is in SAFE, (c) GPS magnification is on 3X, (d) GUN SELECT is in MAIN position, and (e) AMMO SELECT is set to the predetermined battlecarry ammo. We determined during the process of analysis that making individual training objectives for such isolated elements is absurd. Rather, the rule we followed was that training objectives were created for meaningful chunks or units of behaviors. These meaningful "units" are similar to the concept of behavior chunks (Miller, Galanter, & Pribram, 1960), which have more recently been related to the concept of production systems (Anderson, 1982). Anderson argued that the performance of novices may be

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[5]Resnick et al. distinguished the behavioral components from the other levels of the hierarchical analysis by using double lines to outline boxes. In our example and in Appendix E, we use thicker lines for the same purpose. This variation in representation was caused by the fact that our graphics software could not easily produce double lines.

characterized by productions consisting of single sets of conditions and actions. In contrast, expert performance is better simulated by macro productions consisting of multiple sets of conditions and multiple responses. Although the training objectives presented in this report are conceptually similar to such macro productions, the training objectives were derived from a rational analysis of gunnery rather than from an empirical analysis of expert performance.

Finally, Level III of Figure 4-2 comprises the prerequisites to task performance. According to the hierarchy, before learning how to index battlesight range at the TC's station (Objective IIa), the student must know how to (a) visually estimate the range to the target (Objective IIIa) and (b) operate the manual range controls (Objective IIIb). Similarly, before learning how to set the gunner panel switches for a battlesight engagement (Objective IIb), the student must know the correct switch settings for a variety of engagement scenarios (Objective IIIc). Whereas the prerequisite skills are not observable in performance of the task itself, the prerequisites are written in behavioral fashion such that performance-oriented training and testing is applicable for prerequisites as well as for training overt components of the task.

Conclusions

In general, the gunnery domain may be characterized as wide but not very deep, especially compared to the mathematics examples presented earlier. By wide, we mean that the student must know how to perform a wide range of disparate activities. By its lack of depth, we mean that performance is not dependent on a lot of prerequisite skills and knowledges. These structural characteristics of the gunnery domain have some general implications for the acquisition and retention of gunnery skills. For one, initial train-up of gunnery skills should be relatively fast since training is not dependent on complex layers of prerequisite skills. However, skill sustainment may be a problem for two reasons: (a) the sheer extent and diversity of the domain, and (b) the predominance of procedural tasks which research has indicated are especially susceptible to decay (e.g., Schendel, Shields, & Katz, 1978).

The hierarchical analyses of gunnery were performed for some specific purposes: to provide a sequence for training gunnery objectives, to provide a testing strategy, and to integrate device training and testing. The following subsections discuss those purposes and some of the problems that the gunnery domain structure poses for design of the proposed training/testing program.

Training Sequence. The concept of the learning hierarchy was originally developed to identify and sequence intellectual skills for instruction. The sequencing rule is simple: insure that prerequisite skills are trained prior to moving to a superordinate objective. In other words, instructional sequencing may be characterized as building skills from the "bottom-up". For instance, it does not matter whether the student learns first to estimate target range or to operate TC's manual

range controls. However, both prerequisite skills must be trained before training the TC's duties in battlesight gunnery. Thus, the hierarchy identifies constraints to sequence, but, as shown in the example, it does not prescribe a single correct order of instruction.

Because of the width of the gunnery domain, hierarchical analyses specifies only a proportionally small number of required sequences in instruction. Additional rules are needed to sequence instruction. One source of additional sequencing rules is a strategy that may be termed "progressive elaboration" (D. W. Bessemer, personal communication, December 1987). According to this strategy, students start training on some basic procedure without elaboration such as the condition/action options described in the gunnery domain. These elaborations are added only after the basic procedure is well learned. Furthermore, prerequisites for the more elaboration procedures should be trained just prior to the procedure that they apply in order to minimize retention decrements. In the present domain, precision gunnery provides a basic and central gunnery procedure around which a progressive elaboration strategy can be based.

Diagnostic Testing Strategy. Learning hierarchies have also been used to develop a diagnostic strategy (Wang, 1973). For instance, proficiency within a domain may be measured by testing appropriate high level skills. Passing a particular testing objective implies that connected subordinate objectives need not be tested. On the other hand, failing one of objectives would require subsequent testing of lower order skills to identify the locus of the performance deficiency. Thus, a "top-down" approach to testing can be used to efficiently identify the locus of any performance deficiency. The relative flatness of the gunnery domain limits the applicability of this approach; nevertheless, it should still be considered. Testing strategy is discussed more fully in the second half of the chapter.

Evaluation and Integration of Training Devices. The hierarchical analysis will identify discrete units of learning that can be conceptualized as building blocks for acquiring proficiency for the whole domain. These blocks also represent independent units for device evaluations. That is, instead of evaluating devices relative to the whole domain of gunnery, or to hit-and-miss aspects of the domain, they can be evaluated for individually meaningful objectives. Based on these evaluations, recommendations for device use can be targeted at specific units of instruction. The effect of this is to keep recommendations for device use subordinate to considerations of training structure and sequence as described above. Also by targeting evaluations to objectives, testing capabilities can be identified for well-defined domains of performance which have meaning in terms of progressions of skills acquisition. This ensures that training devices are put to optimum use within an integrated program for testing and training gunnery skills.

Testing Approach

Gunnery performance occurs within a man-machine interactive system. From the organizational perspective, individual crew behavior is not the ultimate criterion; system performance and winning engagements are the criteria of most significance. System performance is a product of both machine and persons. Overall system performance is less relevant, however, for purposes of training and testing individual proficiency. That statement is from a psychological, rather than organizational perspective. Both perspectives are important, but for different reasons. They should not be confused. In this research, little emphasis is placed on "hitting targets" as a criteria; the emphasis is on the individual behaviors that are required for the system to hit targets.

Measurement of Conditions, Knowledges, Behaviors, and Outcomes

Our testing approach is based on a simple model of performance relating conditions and cues, knowledge, job behavior, and outcomes of that behavior (White, Borman, Hough, & Hoffman, 1986; Campbell, Dunnette, Lawler, & Weick, 1970). As depicted in Figure 4-3, job behavior is a product of individual knowledge applied to a set of environmental conditions. Performance consequences are determined by the appropriateness of the behavior for the environmental conditions. Evaluation of performance ultimately rests in the value or utility of the consequences that result from any job behavior. Alternative job behaviors are differentially valued by the utility of the various performance consequences they produce.

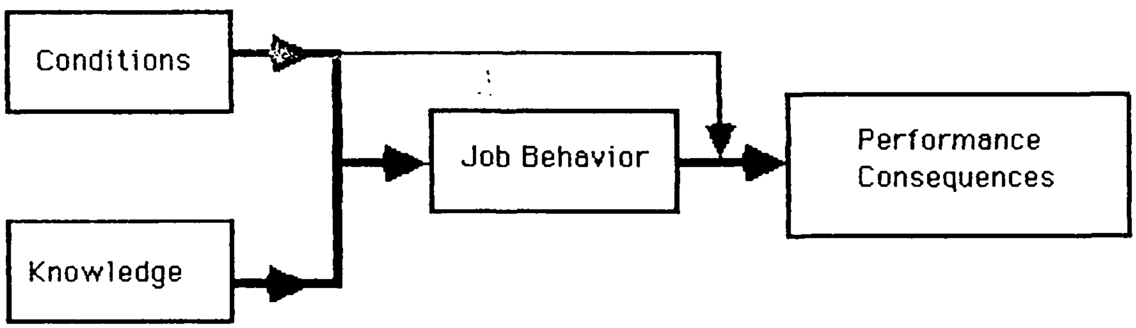

Figure 4-3. Performance model.

In simple procedural tasks, like most of tank gunnery, the relationship between behaviors and performance consequences--for any given environmental circumstances--are known. For performance assessment, this means that it is not necessary to wait for the outcome in order to evaluate the behavior. The values of alternative behaviors are predefined. For other performance domains where the relationship between behavior and job consequences is less certain, the value of any particular behavior can only be determined after the consequences are observed.

The intent of explicating this simple model is to avoid some of the confusion discussed by Boldovici (1979) concerning process from product measurement for gunnery performance. Our model parallels his distinction of process as means and product as end, however we choose to talk in terms of job behaviors instead of process, and job consequences or outcomes instead of product.

One example of the confusion described by Boldovici (1979) is whether assessment of a gunner's sight picture is a process or a product measure. Using the behavior/outcome distinction, a record of a sight picture is not a direct record of a person's behavior. Rather it is a record of the consequences of a person's behavior. Less relevant for the analysis of tank gunnery, but an example used by Boldovici (1979) is the assessment of a diver. His argument is that the "product" of the diving is a splash in the water, a difficult entity to evaluate. Thinking in terms of consequences, we would argue that the intended outcome is the aesthetic pleasure of the spectators. Scoring of diving competition is a judgment of behavior; however, the scoring differentially values dives in terms of the forms and techniques that novice and seasoned spectators can appreciate. Thinking in terms of consequences rather than products broadens our perspective on job performance in other ways as well. Boldovici (1979) expresses some dissonance with the notion that a chambered round, the result of loading, is a "product." Again, if one thinks in terms of consequences, a loaded round makes perfect sense as the consequence of loading.

Given that our primary purpose for testing individual performance is to provide information for training and skills acquisition, the unit of analysis we are most interested in is individual job behavior. Individual behavior represents the only way a crewman can exert his influence and perform his role in the tank, whether the immediate relationship is with other crew members, platoon leaders, or the tank itself. Behavior is what the individual can and must change in order to affect crew performance outcomes. Alternative levels of analysis include assessment of knowledge requirements for appropriate behavior, and assessment of the consequences of behavior. Assessment of consequences and assessment of knowledge can and should augment the assessment of behavior but only under certain circumstances.

There are many simple behaviors that are presumed to be part of all soldiers' repertoire, e.g., flipping a toggle switch. If a soldier has the knowledge that the behavior is required, it is safe to assume the behavior can be executed. In fact, instructions like "turn the switch on"

that actually refer to the consequences are given as instructions about behavior. In other cases, this assumption is unreasonable. That is, a person may know that a tennis ball is to be served within designated boundary lines, but that does not mean that the person can execute the correct behavior. That is not to say that knowledge of where to serve the tennis ball is not important. In fact, if an athletically adept person does not know which of the court lines define the serving area, he/she will serve it in the right place only by accident. Our theoretical model specifies that knowledge is always a necessary, but not always a sufficient condition for appropriate behavior. If it is sufficient, then assessment of that knowledge may be substituted for testing the behavior. On the other hand, if the behavior is complex, requiring practice (a skill as defined in Adams, 1987), then assessing only the supporting knowledge is insufficient.

For some behaviors, the assessment of performance consequences may provide an acceptable index of job behavior. Two conditions jointly influence the assessment: (a) the complexity of the behavior, and (b) the strength of the relationship between the behavior and the consequences of interest. In some cases, the behaviors are simple and outcomes are predictably related to behaviors. Given that a switch is "off" and should be "on," assessing the position of the switch after performance may reasonably be accepted as an index of whether the appropriate behavior occurred or not. If there are no automated returns or positioning wired into the switch, there is no contamination in the measure. Furthermore, failure to perform the procedure may be corrected by instructions related to the outcome, e.g., tell the person to "turn the switch on."

The tennis example provides a somewhat different illustration. The behavior is not simple. It is not easily described or easily recorded for evaluation. Furthermore, there are undoubtedly variations in technique that all result in the ball landing within the serving area. On the other hand, barring poor equipment or weather conditions, the trajectory and landing of the ball is a direct consequence of the behavior. Therefore, whether the ball is in-bounds can provide an evaluation of the satisfactoriness of serving technique (ignoring for the moment speed and spin of the ball). But because the behavior is not simple, providing instructive feedback can be a problem. Unlike the switch example, simply repeating the desired outcomes does not tell us how to change our behavior (assuming we have been trying to get the ball in the serving area). Thus, the location of the ball's impact may be an acceptable proficiency measure, but it is not a very good diagnostic measure. More direct behavior observation is needed to provide corrective feedback.

Hitting a baseball is another example of a complex behavior, but this time the consequence is not as directly connected to the behavior for three reasons. First, there are a variety of environmental conditions that also influence performance consequences. That is, the hitter may or may not have assessed the situation correctly (i.e. fast ball versus curve or off-speed pitch). Perfect execution of the behavior for hitting a fast ball will result in a miss at a slower off-speed pitch. Or, if contact is made, where the ball is hit combined with the ability of the fielders will

influence whether or not the batter arrives safely on base. Thus, while batting average is an accepted index of hitting proficiency, it ignores potential contamination due to the abilities of opposing pitchers and fielders. That is, a hitter should want to be on the team with the strongest pitchers not only because their chances of winning are increased, but also because they won't have to face those pitches and their batting averages will be higher. Second, missing a pitch may be due to poor batting technique or poor judgement. Thus, in this example, getting a hit or making an out is a contaminated measure of proficiency, and behavior observation alone may lead to ambiguity in diagnosing the cause of an errant swing, e.g., should instructions be behavioral (let up on the swing) or cognitive (watch for the slow pitch). Third, within limits, there are a variety of ways to hit a baseball. Some batters choke-up, some don't; some use an open stance, others a closed stance. Variations in specific behavior techniques are used by different hitters depending on what consistently gives them the most solid contact with the ball. This suggests that successful measurement plan will include recording of conditions (what pitch was thrown), hitter's knowledge (discriminating fast balls from off-speed pitches), observing the swing, observing where and how hard the ball was hit, and observing whether or not the hitter made it to base. While the later event is the most important for the outcome of the game, it is the least important assessment for instructing the batter. Furthermore, no one measure alone is sufficient. Useful feedback must be based on inferences about hitters' ability to judge pitches, their swing, and how well they make contact.

Thus, while behavior is the unit of analysis that is of most interest, it may or may not be the unit of analysis on which a measurement system should focus. Other things being equal, direct assessment of behavior is preferred. But that is not always so. In some cases knowledge assessment may be easier to acquire and may suffice as an appropriate substitute. In other cases, it may be required, or not necessary. Likewise, in some cases assessment of outcomes or consequences may suffice, whereas in others it is too contaminated or too difficult to obtain. Outcome measures are seductive in that they often tap the level of analysis of most interest to system designers and planners. For example, it takes "steel on target" to win battles, and tacticians must plan according to steel on target capability. For individual or crew level assessment, steel on target is contaminated by system errors and measurement difficulties. More importantly, it does not yield the kind of diagnostic information needed to provide corrective feedback.

Measurement Classification Rules

The principles underlying the above discussion are not hard and fast rules. For example, it is a subjective judgment whether an outcome is the result of too many factors other than the behavior of the individual to be a useful focus of measurement of individual performance. However, the principles do provide useful heuristics for specifying the kinds of measures most likely to be useful in the training context. That is, it is possible to analyze the performance elements in the gunnery domain and

specify the kind of measure or measures that seem best suited to measuring proficiency and providing feedback. Table 4-1 provides a summary of these rules.

Table 4-1

Factors Affecting Measurement Mode Selection for Individual Assessment

1. Cognitive requirement:
   a. Linear procedure, simple reaction. Feedback about knowledge is trivial.
   b. Choice reaction and behavior adjustment required. Assessment of the appropriateness of choice is needed to diagnose incorrect performance.

2. Behavior requirement:
   a. Simple. Feedback about behavior per se is trivial.
   b. Complex. Direct assessment of behavior is needed to diagnose incorrect performance.

3. Consequences:
   a. Strong association with behavior; outcomes primarily dependent on behavior. Outcome measures may be sufficient for feedback if the behavior is simple.
   b. Weak association; outcomes heavily dependent on factors other than individual's behavior. Outcome measures are too contaminated to be certain about the behavior that took place.
   c. Alternative associations. There are alternative behaviors for obtaining desired outcomes. Can not infer what behavior took place from observing outcomes.

There are twelve combinations of the three factors affecting measurement mode. However, for the combinations that involve alternative behaviors, both simple and complex behavior types require observation of the behavior to ascertain what was done. Thus, no distinction in type was made between simple and complex behavior when alternative behavior associations with outcomes could occur. As a result there are ten types of elements. The types and their measurement specification rules are identified in Table 4-2.

Two additional classifications of performance elements are added to the ten to cover task elements that involve no overt behavior and no immediately observable consequences. These cases still fit the model; the difference is simply that neither the behavior nor the consequence is

Table 4-2

Measurement Specification Rules

Step Type	Decision	Behavior	Consequences	Measurement Requirement[a]
Overt Behaviors:				
1.	No	Simple	Strong Assoc.	K, B or O will suffice
2.	No	Simple	Weak Assoc.	K or B will suffice
3.	No	Complex	Strong Assoc.	B necessary; O for proficiency only
4.	No	Complex	Weak Assoc.	B necessary
5.	No	Either	Alternative Associations	B and O necessary
6.	Yes	Simple	Strong Assoc.	K necessary; B or O for proficiency
7.	Yes	Simple	Weak Assoc.	K necessary; B for proficiency
8.	Yes	Complex	Strong Assoc.	K and B necessary; O for proficiency
9.	Yes	Complex	Weak Assoc.	K and B necessary
10.	Yes	Either	Alternative Associations	K, B and O necessary
Covert Behaviors:				
11.	No	Observing	Information	K for new information
12.	Yes	Analyzing	Information	K for analysis rules and K for new information

[a]K = Knowledge assessment; B = Behavior assessment; O = Outcome assessment

ordinarily observable. There are covert behaviors and individually private consequences. In each case, covert observation or analysis of environmental cues provide the individual with new information for use in performing later task elements. These two kinds of task elements could have been eliminated by combining them with the next overt behavior in the procedure. However, in the instances where such elements appear, the requisite knowledge or the analysis process was judged sufficiently complex to warrant attention apart from the subsequent overt behavior.

By categorizing each gunnery element by type, measurement requirements become implicit. In order to classify elements, the most immediate knowledge requirement and the most immediate consequence were considered along with the overt behavior. Examples of each category of element are presented in Table 4-3.

Table 4-3

Measurement Category Examples for the M1 Tactical Gunnery Domain

Step Type	Crew Member	Activity	Description	Comments
1.	Gunner	2	Index battlecarry ammo using AMMO SELECT switch	Simple action; outcome is switch position.
2.	TC	4.1	Issue Fire Command	Outcome is crew response which depends on crew as well as TC, therefore outcome association is weak.
3.	Gunner	4.1	Squeeze trigger(s) (reticle on target)	Outcome is sight picture, strongly association with behavior. Behavior is complex; coaching needs to consider such things as flinching, etc.
4.	None of the tactical gunnery elements were classified in this category.			
5.	Loader	4.1	Check turret ring	Behavior is simple, but potential outcomes of checking versus not checking very. If there are no obstructions, there is no outcome indicator of whether or not loader checked ring.
6.	TC	2.2	Prepare tank sketch card	Must decide what to draw, but sketch card is a direct record TC's work.
7.	Gunner	8	Aid in adjusting TC's weapon	Must determine what directions to give TC, but TC may or may not follow those directions.
8.	Driver	3.1	Follow wingman concept; react to formation changes	Position of tank is outcome.

(table continues)

Step Type	Crew Member	Activity	Description	Comments
9.	TC	4.3	Direct GNR onto target using one of the following techniques: . use verbal commands: . use Target Reference point . announce WATCH MY TRACERS and use CAL .50 to point to target	TC decides what to and must do if correctly, but outcome (gunner identifying target) also depends on gunner.
10.	TC	2	Supervise/assist in boresighting main gun	Requires decisions during procedure, behaviors are complex and outcome (boresighted tank) depends on other crew members.
11.	Gunner	3.2	Estimate range to evaluate LRF return	Gunner observes range so that he can use it later when evaluating LRF return.
12.	All	3.2	Identify target(s) making the following determinations: · IFFN · nomenclature	Determination later used for target confirmation.

Measurement in the Context of Gunnery Activities

So far in the discussion, we have addressed testing as if we were interested in only one element of gunnery at a time. There are, however, other considerations that have to do with the fact that any one element is significant only because it is part of a string of elements that make up an integrated unit of performance. The most important of these considerations is that testing should be designed not around elements, but by activities and objectives. That is, to isolate an element and remove it from the context of the rest of the elements in the sequence to which it belongs removes many external and internal cues, e.g., kinematic cues related to movement sequences (Adams, 1987). According to cognitive learning theories such as Anderson (1982), those persons with high levels of skill do not perform in element-by-element fashion, but by higher order units of behavior or macro productions (see previous section). Thus, test administration should be organized at the macro production level, arranged following the hierarchical analyses as objectives. Furthermore, all elements must be represented in the test because a production is defined by its individual elements and omitting elements defines a different production.

Having introduced the concept of macro productions, it is necessary to go back and elaborate somewhat on our concepts of knowledge versus behavior testing. In the context of chunking and productions, we do not mean to imply that testing "knowledge" requires a written test of some kind. Procedural knowledge, particularly if the procedure is well learned is not necessarily verbal nor easily accessed by verbal means (Anderson, 1982). Our distinction between elements that can be tested by knowledge assessment versus those that require behavior assessment is not based on how the element is coded in memory, but rather on how easy it is to translate the element for verbal description to behavior. Elements that we label as appropriate for knowledge testing are elements that are easily described (verbally) and then executed. Thus, failure to execute such an element during performance of the procedure simply implies that the sequence has not been properly stored in some part of memory, whether that is verbal or some other part. Acquisition of those elements is most concerned with compiling the elements in proper sequence. Elements that we coded as requiring behavior assessment are those that require greater motor skill, and consequently more attention to acquiring correct motor behaviors. The two categories of elements are not clearly discrete. They are, however, useful distinctions for guiding appropriate selection of feedback information. For "knowledge" elements, we are concerned with whether or not the behavior occurs. For "behavior" elements, we have an additional concern with how well or which behavior occurred.

Other Testing Considerations

Other testing considerations introduced at the objectives level are test use, speed of performance, hierarchical arrangement of objectives and activities, testing performance under different environmental conditions, and use of composite scores.

Test Use. Performance testing in the training context has two potential uses: (a) diagnostic testing to pinpoint skill deficiencies, and (b) proficiency testing to assess level of performance. Certainly the two uses are not mutually exclusive, but there are two major differences having to do with treatment of scores and use of sampling. It has been argued above that testing should be organized around activities and that all elements should be included. For diagnostic testing, that requirement is extended: Each element must be scored and the scores be made available. For proficiency estimation on the other hand, some sort of aggregate or total score (e.g. percent of elements performed correctly) is more appropriate. Obviously, a test can provide both. However, the fact that individual element scores are not needed for proficiency testing creates the possibility of sampling activities and inferring other scores based on the sample observed. For example, if the relationship between single target gunnery and fire adjustment is sufficiently strong, fire adjustment proficiency could be adequately estimated from single target gunnery test scores. However, specific deficiencies in fire adjustment could not be identified. Thus, diagnostic testing requires scoring and feedback of all elements and activities, whereas proficiency testing allows for sampling of activities and use of summary scores.

Speed. Speed of performance is an important metric for essentially all of the gunnery activities, particularly the engagement activities. Acquisition time, opening time, and hit time are the times most often assessed. Each of these represent the time it takes for the crew to execute a series of task elements. Times to execute other elements, either individually or grouped, can be imagined. There are limits to what is possible to time on the tank with traditional techniques, but a scorer with an electronic stopwatch can record as many events as there are memories in the watch. For example, depending on his ability to see and hear, a scorer on a tank range could capture times for (a) when the TC announces "GUNNER," (b) when the gunner announces "IDENTIFIED," (c) when the gunner lases, (d) when the TC announces "FIRE," (e) when the gunner fires (f) when the loader announces "UP" for the subsequent round, (g) when the gunner announces his observation, and (h) when the TC announces his next command. A difficulty is maintaining a record of the sequence of events. Extending the idea to sophisticated simulators, however, one can imagine performance profiles giving time to execute each element. Such profiles could be useful to pinpoint particular elements in the procedure that seem to be slowing down a crew's performance.

There are two caveats regarding time as a performance metric. First, time by itself is an insufficient metric. It may show what behaviors are slow, but it does not provide any information about why. The second has to do with the pervasive speed and accuracy trade-off: For many tasks, increased speed leads to reduced accuracy, and vice versa. The question becomes what combination of speed and accuracy is best. That is, if utility of performance is viewed as a function of speed and accuracy, what is the function? In general, the rule seems to be "the faster the better as long as the behaviors are performed correctly." For example, speed as a measure of boresighting proficiency make sense only for discriminating among crews who can in fact boresight the M1.

For those portions of the gunnery domain that involve engaging targets, there has been considerable debate about how time and performance accuracy should be combined into a performance utility measure (Witmer, 1986; D. W. Bessemer, personal communication, September 1982). This debate is most relevant to the organizational perspective of assessment performance for the purpose of analyzing battle capabilities where the trade-off between speed and accuracy can be evaluated for its impact on mission success. Those discussions are less relevant for our purposes and will not be extended here. Instead, we are concerned with how to use speed and accuracy feedback to best facilitate skill acquisition. According to common "stage" notions of skills acquisition (e.g., Fitts, 1964; Anderson, 1982), performance accuracy precedes performance speed in the skill acquisition process. Furthermore, instructions, feedback, and payoffs for emphasizing speed lead to decrements in performance accuracy (Fitts, 1966; Howell & Kreidler, 1964). Thus, we will adopt the training prescription that accurate performance should be the initial emphasis of practice, with speed emphasized only after correct behaviors are acquired. Consequently, we will not make complex prescriptions about how to mix accuracy (from either knowledge, behavior, or outcome sources) and time measures. Instead, time should be used during practice only when the task elements are performed correctly.

Hierarchical Arrangement of Activities. The tactical gunnery domain has been described by partitioning it into activities. In addition, our hierarchical analysis delineating training objectives further divides the domain within and across activities. For complete diagnostic testing, all activities and all elements within them must be testable in order to be able to provide specific diagnostic feedback about what needs remediation.

The hierarchical arrangement of the activities of the M1 tactical gunnery domain (detailed in previous section) is based on the notion that there are dependencies among the activities. That is, proficiency on some activities may be prerequisite or propadeutic for the performance of other activities. This information may be used in testing applications to shorten testing time through adaptive testing strategies. That is, if the hierarchy is valid, then testing key activities first may provide information about the likely performance in other activities. For example, if a gunner can engage multiple main gun targets from a moving tank, there may be a very high probability that he can engage single main gun targets. Thus, testing performance with multiple targets first would eliminate the need to test single targets for crews who are proficient at multiple targets. On the other hand, given that the domain of tactical gunnery is broad rather than deep (see previous section), there may not be many opportunities to infer performance in one area from that in another.

Testing samples of the domain may be appropriate for less intensive proficiency level determination. Sample requirements are determined by domain heterogeneity. The less the covariation among all performance elements in the domain, the more elements must be observed to obtain reliable measurement.

In addition to hierarchical dependencies, there may be other reasons for covariation among performance scores for the various activities increasing the possibility of generalizing proficiency from a sample of activities to the entire domain of activities. For example, covariation may result because many of the activities tend to be practiced together. Note that correlations among activity performance scores that are the spurious result of experience do not support any conclusions about transfer of learning between activities. The need to specifically learn each activity is maintained as well as the need for assessing all elements for diagnostic testing. Sampling of activities is appropriate only when measuring proficiency.

<u>Domain Conditions</u>. Organization of the gunnery activities was based on the parameters of the gunnery environment (see Chapter 2). Separate activities were created to reflect the impact that some of the varied parameter conditions have on gunnery behavior requirements. These conditions were labeled primary conditions. Also, a number of secondary conditions were identified that do not directly influence what behaviors should be performed, but do influence how and/or how well they are executed. How well performance under many of these difference conditions relate to each other is unknown.

For some activities, performance under the different secondary conditions may be ordered by varying degrees of difficulty. For these activities, it is appropriate to describe level of proficiency in terms of conditions and standards. For other activities and parameters, there may be no necessary ordering by difficulty, but simply a correlation. In such cases, when not all conditions can be tested, sampling is appropriate.

The two categories of parameters (primary and secondary) have different implications for testing. Recall that primary conditions are those that must be presented in order to branch a crew through each of the parts for the M1 tactical gunnery domain. Specification of conditions of these parameters creates the environment that a crew must attend to in tactical gunnery. These may be conceived of as essential foreground elements in the gunnery environment. In contrast, the secondary parameters are background elements of the gunnery environment that may influence performance to an unknown degree. The foreground conditions must be represented in a simulation if all of the gunnery activities and options within the activities are to be covered in tactical gunnery training and skill assessment. Requirements for representation of the background conditions are less certain, however assessing proficiency under varying background conditions will increase the reliability of measurement and therefore increase confidence that proficiency scores can be generalized to a variety of circumstances.

<u>Composite Scores and Outcome Scores</u>. We have argued that for diagnostic testing feedback needs to be available for every element of performance. On the other hand, summary information is more convenient for conveying general competence. Thus, detailed scores can be aggregated into composite indices of performance at various levels of abstraction. Because they are an abstraction, the primary concern of a composite score

is the underlying logic used to turn a set of scores about individual elements of behavior into one index. It is important than that composites be logically constructed with meaning that is easily understood and is appropriate.

A composite score is a single score constructed from a number of other scores by a series of rules or by a mathematical formula. The set of rules or the formula gives the composite score its meaning. It is useful to think of that meaning as expressing the value or utility of the particular aggregation of behaviors. Thus, the composite score can be viewed as the resultant of a utility function. But, utility for what? There are several kinds of decisions and purposes for composite scores, including general training management decisions, personnel placement, mission planning and analysis, crew motivation, and training progress indices.

Two different kinds of utility functions may be identified in relation to these uses. The first is a derivative of the performance model presented in Chapter 4. That is, composite scores may express the utility of a given set of behaviors in terms of the value of the expected consequences or outcomes of those behaviors.[6] The nature of a composite is such that there may be trade-offs; that is, equal functional value may be assigned to more than one pattern of behavior. The formula of constructing the composite score should equate those alternative patterns. There may be trade-offs (at least for some objectives) such that faster but somewhat less accurate behaviors will lead to as much "productivity" as slow but more accurate behavior. Hit rate (controlling for equipment and ammunition errors) is a product of accurate behaviors (including everything from target acquisition to fire adjustment) and speed of executing those behaviors. Within limits, there are trade-offs between speed and accuracy (expressed in a non-linear ration function such as hit per time or time to hit) resulting in equivalent utility. Thus, one type of composite may be constructed to represents crews' current level of proficiency in the real world setting according to the expected consequences of their behavior.

The second kind of utility function expresses performance in terms of training value or expected increment in performance as a result of a practice trial. In a sense, this is a derivative of the first option, but it shifts attention from a real world focus to a training focus. One reason for making the distinction evolves from the previously cited research concerning the speed versus accuracy trade-off. We have argued that when practicing for performance improvement, speed should not be

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[6]We use the term "expected consequences" in recognition of the fact that performance consequences are a product of crew behaviors plus equipment functioning. Thus, "correct" behaviors may not always lead to desired consequences. However, from the standpoint of the crew instruction and evaluation, the behavior was no less correct. Similarly, incorrect behaviors may, by chance, lead to desired outcomes, but that does not make those behaviors "correct."

emphasized until procedural accuracy is achieved. Thus, for performance improvement, the utility function may not incorporate the same speed and accuracy tradeoff as the proficiency function. In the early stages of learning, the training payoff for any practice trial may have little to do with speed, and thus speed should not be incorporated in the composite (e.g., receive zero weight in a linear utility function). Later in training, as some degree of accuracy increases, adding speed during practice is necessary and should be included in a composite. At present, not enough is known about the acquisition process to make specific recommendations concerning when to begin emphasizing speed.

There may be other such trade-offs in constructing composite scores. The important point is that a composite score should be constructed for a specific purpose. Two purposes have been explicated: (a) evaluating the utility of performance in terms of expected consequences, and (b) evaluating practice in terms of skills acquisition. Composite scores that express performance in terms of real world utility support general training management decisions (e.g., are crews at desired levels of performance or should more time be allocated for training?) and mission planning and analysis (e.g., given current proficiency how much fire power can be expected?). Furthermore, they can be used to influence general levels of crew motivation by appropriate connections with extrinsic (awards, time-off) and intrinsic (self-competence, esprit de corps) reinforcements. Composites constructed to represent utility for improved performance made be used for more specific training progress determinations and can be used to reinforce specific response patterns during training. Construction of an equation for a proficiency composite is a relatively straightforward operations research problem. Construction of a utility equation reflecting training value of a practice trial is a psychological problem for which a solution is not readily available because research on gunnery training has focused on transfer issues rather than on patterns of skill acquisition.

Conclusions

A number of basic testing issues for the M1 tactical gunnery domain have been discussed. These included the assignment of knowledge, behavior or outcomes assessments for every element as appropriate for diagnostic or proficiency test use, with testing of elements embedded in testing of activities. Scoring of all elements should be available for diagnostic use, however selective scoring may be possible to estimate proficiency level. Selective testing may be guided by activity hierarchies when prerequisite or propadeutic relationship are involved, otherwise, sampling may be used. In addition, secondary conditions may be used to define levels of difficulty within affected activities. Finally, composite scores may be constructed to provide summary information on performance, if careful attention is given to the meaning of composite scores.

CHAPTER 5

IDENTIFICATION AND EVALUATION OF DEVICE FEATURES REQUIRED FOR TRAINING

The purpose of the present chapter is to evaluate the four gunnery training devices that were designated for study: VIGS, TopGun, U-COFT, and SIMNET. The chapter provides an examination of device features in order to evaluate their utility for the proposed training/testing program. Training simulator features are commonly divided into two general classes: fidelity features and instructional features. Fidelity features are defined as those simulator components that enable the simulator to mimic the operational equipment. In contrast, instructional features are those simulator capabilities that facilitate the instructional process. Accordingly, the present chapter is divided into two major sections that correspond to this distinction. Before getting into those topics we begin with an introductory section that describes the four devices and the procedures used to evaluate them.

Evaluation Methods

Two disclaimers should be stated at the outset of the description of our evaluation methods. First, the purpose of our evaluation was not to mathematically determine the "optimal" or "best" device for training gunnery. To make such a determination would require quantitative information about device effectiveness and costs that is neither available nor easily obtained. [See Sticha, Blacksten, Knerr, Morrison, and Cross (1986) for a detailed discussion of the rationale and requirements for such an analysis.] Rather, our purpose was to compare the relative strengths and weaknesses of specific gunnery devices for training the domain of gunnery as defined in previous chapters. Thus, a qualitative comparison of devices was deemed appropriate for the evaluation of training features described in the present chapter as well as for the evaluation of testing features described in the next chapter. Second, the findings were based on information that was available at the time of the evaluation (April - August 1987). Some of the conclusions may not hold because of device software updates and design changes that have occurred since that time period.

Devices

The four designated training devices are all computer-based systems designed to train M1-related skills. Except for SIMNET, each is designed to train gunnery. The latter is primarily designed to train platoon through battalion level tactics. Nevertheless, SIMNET simulates many of the conditions and actions related to armor gunnery. Each of the devices is described in more detail below.

VIGS. The Videodisc Integrated Gunnery Simulator (VIGS) is a training device that uses "intelligent" videodisc technology, i.e., videodisc target images are controlled by a microcomputer. Designed to sit on a table top, the VIGS gunner's station includes the gunner's primary sight (GPS), power control handles, and some of the controls and switches that appear in the tank. The M1 version of VIGS is currently under development by the Educational Computer Corporation (ECC) and is scheduled for fielding in FY88. The version of VIGS that was examined was the prototype M1 VIGS that was designed by Perceptronics (MK-1).

TopGun. Developed as a successor to Battlesight (an M60A1 gunnery trainer), TopGun was developed jointly by ARI and DARPA as a research device to investigate the use of an inexpensive, arcade-type video game for acquiring and sustaining tank gunnery skills. TopGun is similar to VIGS in that it focuses only on gunner duties. Approximately 25 M1 version TopGun devices will be delivered for evaluation in FY88.

U-COFT. The Unit Conduct-of-Fire Trainer (U-COFT) is a high fidelity, computer-based gunnery simulator for training tank commanders and gunners. The major components of the U-COFT include a crew compartment that is a close simulation of gunner and tank commander stations, an instructor-operator station (IOS) where the trainer can control training events, and a general purpose computer that supports both image generation and training management functions. In descending order of priority, the four purposes of U-COFT are (a) to sustain year-round gunnery performance, (b) to cross-train loaders and drivers in gunner duties and gunners in tank commander duties, (c) to transition train armor personnel to the M1 or M1A1 tank, and (d) to provide nonarmor personnel (cooks, mechanics, etc.) basic gunnery training to serve as battlefield replacements (Griffin & Kuma, 1985). In contrast to the other three devices, the U-COFT is presently in the inventory of Army training devices. Fielding plans call for U-COFT to be sent to every armor battalion and cavalry squadron and to be integrated into their unit training programs.

SIMNET. SIMNET (Simulated Networking) is a large scale research project in interactive networked simulation sponsored by DARPA and TRADOC. SIMNET provides a simulation of the battlefield allowing armor crews to participate in platoon, company, and battalion-level force-on-force engagements. A SIMNET station consists of a driver's compartment and a crew compartment with gunner, loader, and commander stations. Thus, SIMNET is the only device of the four that simulates all four tank crew positions.

Procedures and Materials

In order to obtain an accurate impression of device capabilities and limitations, we attempted to examine and operate the four armor training devices under consideration (VIGS, TopGun, U-COFT, and SIMNET). Unfortunately, VIGS and TopGun are not yet available in M1 form. For TopGun, we examined the predecessor device (Battlesight), which is designed to

simulate M60A1 tank gunnery. In addition, we were furnished design specifications for the M1 version of TopGun. For VIGS, we examined the prototype M1 VIGS that was produced by Perceptronics (MK-1). Two examples of VIGS courseware were examined: (a) demonstration courseware produced by Perceptronics showing a variety of friendly and threat targets under day and thermal channel viewing conditions, and (b) experimental courseware produced by ARI showing a variety of thermal targets. The production model of the M1 VIGS is currently under development by the Educational Computing Corporation. Design specifications for the production model were not available at the time of evaluation.

Fidelity Features

For transfer of training to occur, we assume that there must be some sort of correspondence between training device and operational equipment. This assumption agrees with common sense notions of training as well as with basic theoretical concepts of transfer. As early as 1903, Thorndike espoused the theory of identical elements to explain transfer phenomena. He maintained that the amount of transfer depends on the number of elements in the training task that are identical to those in the transfer task. Identity was defined in terms of functional as well as physical similarity between the two tasks. Similar transfer principles are implicit in models that the Army has developed to predict the effectiveness of training devices. (For a review these models, see Tufano & Evans, 1982.) These models, known collectively as TRAINVICE, all provide for an analysis of the physical and functional similarity between the training device and the operational equipment and/or an analysis of the skills that are common to performance on the device and on the equipment. The results of these analyses of devices are used to predict the amount of transfer that will occur to the operational equipment.

Similarly, we assume that the validity of training devices as media for measuring job performance is dependent on the fidelity of the device with respect to the operational equipment. This assumption is based on the principle of content validity (Cronbach, 1960). A content valid test is one that provides a representative sample of the to-be-measured construct. Therefore, the best predictor of job performance would be a test that includes elements of the job itself--the concept of the job sample (Wernimont & Campbell, 1968). Using this reasoning, Black and Graham (1986) argued that armor simulators function not only as training devices, but also provide job samples for predicting the performance of armor crewmen. The relation of device fidelity to performance measurement is discussed more fully in Chapter 6. Nevertheless, our evaluation of device fidelity must be mindful of the fidelity requirements for testing as well as training.

The devices analyzed in the present chapter were all designed to simulate operation of the M1 tank. As a result of these deliberate similarities, there are many device characteristics that promote positive transfer to the M1 and positive correlations between the performance on

the device and performance on the actual equipment. These device characteristics may be termed positive transfer and positive correlations sources, respectively, in that they tend to increase transfer and correlation coefficients. Despite a lack of empirical support for positive transfer and correlation (see Chapter 3 for review), the devices have innumerable sources for positive transfer and correlation.

One reason for the lack of empirical positive transfer and correlation coefficients is that there also exist specific dissimilarities between the device and the operational equipment. These dissimilarities may provide problems that could constrain or possibly contraindicate the use of the device for training and testing certain aspects of gunnery (Boldovici, in press). For instance, certain device characteristics could lead to behaviors that are unsafe on the operational equipment. Analogous to these transfer problems are device characteristics that penalize appropriate behavior. These latter characteristics may restrict or constrain the use of training devices as performance measurement instruments. These dissimilarities are referred to as negative transfer and correlation sources in that they tend to reduce or attenuate transfer and correlation coefficients. Because of their crucial impact on device applications, these negative sources are of particular concern in the present evaluation and are operationalized as follows:

1. A <u>negative transfer source</u> is defined as a training device characteristic that results in a novice learning an inappropriate (particularly unsafe) habit that could transfer to performance on the operational equipment.

2. A <u>negative correlation source</u> is a training device characteristic that results in an expert being penalized for behaving in a manner that would be appropriate in the operational equipment.

<u>Evaluation of Device Fidelity</u>

The results of the evaluation are divided into two sections: (a) a description of the general capabilities and limitations of devices, and (b) a discussion of the more specific sources of negative transfer and correlations.

<u>General Capabilities and Limitations</u>. To describe the more general characteristics of devices, fidelity was examined in terms of the two primary dimensions of the gunnery domain: conditions and actions. For the conditions dimension, we determined whether devices could simulate each condition within the parameters described in Chapter 2. The detailed results (in Appendix F) consist of a table of "YES" and "NO" entries corresponding to instances where the device could or could not simulate a particular condition. These detailed results are summarized in Figure 5-1, where symbols are used to summarize the extent to which each gunnery parameter is simulated by devices. Each rating was based on the proportion of conditions within parameters that are simulated. The

PARAMETERS	DEVICES VIGS	TopGun	U-COFT	SIMNET
Target Type	○		◒	○
Target Movement	◒	●	●	●
Target Cover/Concealment	◒	●	●	●
Target Array	◒	●	◒	●
Target Orientation	●	●	●	●
Target Range	◒	◒	●	●
Target Sector		◒		●
IFFN	◒	●	●	●
Enemy Activity		○	○	◒
NBC Conditions				
Equipment Status		○	◒	○
Number of Crewmen			●	●
Supply Shortages	◒	◒		●
Mission			●	●
Fire Control				●
Movement Formation				●
Special Engagement Requirements				●
Space				●
Visibility	◒	◒	◒	
Terrain	○	○	●	●
Terrain Vegetation	◒	○	●	●

● All conditions (100%) are simulated by the device.

◒ Most conditions ($\geq$ 50%) are simulated by the device.

○ Some conditions (< 50%) are simulated by the device.

No Symbol No condition or only the basic or null condition is simulated by the device.

Figure 5-1. Summary of conditions simulated by gunnery training devices.

arbitrary breakpoints of 100, 50, and 0 percent used as rating were sufficient to describe the similarities and differences among devices.

Similarly, the extent to which every action identified in the domain could be performed on the devices was determined by answering some "YES/NO" questions. The questions were all phrased such that "NO" responses required comments whereas "YES" responses did not. The questions were addressed in the following order: (a) Can the action be performed or practiced on device? (If not, do not answer any more questions.) (b) Can every subcomponent (step) of the action be performed or practiced? (c) Are the stimuli and responses equivalent to those on operational equipment? And (d) Should performance on the device be positively related to performance on the operational equipment? The responses to these questions and the detailed comments are found in Appendix G.

Figures 5-2 to 5-3 summarize the answers to questions a through c. Answers to question d are discussed in the next section. Figure 5-2 compares all four devices on gunner task elements. Figure 5-3 presents a comparison of U-COFT and SIMNET on tank commander elements, because only these two devices provide for tank commander participation in gunnery. Finally, Figure 5-4 presents a summary of loader and driver elements for the SIMNET device, the only device that provides for these duty stations. In each figure, device fidelity is described by two related ratings. The first rating (round symbols) corresponds to the concept of comprehensiveness, i.e., the proportion of activity elements that can be performed or practiced on the devices. This proportion was determined by dividing the number of elements which can be performed on the device (question a above) by the total number of elements. The second rating (square symbols) may be interpreted as device realism in that it describes the proportion of performed/practiced elements that are <u>not</u> subject to degraded fidelity conditions. This second rating was defined then as the number of elements without missing subcomponents (question b) or whose stimulus or response components were not altered (question c) divided by the number of elements that may be practiced (question a). Thus, the realism rating should be interpreted only in conjunction with comprehensiveness, because the former rating is conditional upon the latter. For instance referring to Figure 5-2, VIGS and TopGun receive the highest realism rating for elements of the PREFIRE checks that it simulates. However, the comprehensiveness ratings indicate that those devices only a few of the elements can be simulated at all. Thus, device fidelity is actually quite limited for this activity.

Results from the preceding analyses lead to a number of generalizations concerning device capabilities and limitations. We begin with some generally positive statements of device capabilities:

1. Over the entire domain of gunnery conditions and actions, U-COFT provides a very comprehensive and realistic simulation of gunnery conditions and actions. Considering the purpose and the cost of U-COFT, this is not an unexpected result.

GUNNER ACTIVITIES	TRAINING DEVICES: VIGS	TopGun	U-COFT	SIMNET
Prepare Stations for Operation (PREOPS)	○ □	○ ■	◒ □	○ □
Perform Prepare-to-Fire (PREFIRE) Checks	○ ■	○ ■	● ⬓	◒ ⬓
Acquire Target(s)	○ □	◒ □	◒ ⬓	◒ ⬓
Engage Single Target from the Offense Using Precision Gunnery	N/A	N/A	◒ ■	◒ ⬓
Engage Single Target from the Defense Using Precision Gunnery	◒ ⬓	◒ ⬓	● ■	◒ ⬓
Engage Targets Using TIS	◒ □	◒ ■	● ■	N/A
Adjust Fire	◒ ⬓	◒ ⬓	● ⬓	● ⬓
Engage a Single Target with the Coax	◒ ⬓	N/A	● ⬓	N/A
Engage Multiple Targets with the Main Gun	● □	● ■	● ■	● ■
Engage Targets with the Cal .50	N/A	N/A	● ■	N/A
Engage Targets Using Battlesight Gunnery	◒ ⬓	N/A	● ■	● ⬓
Engage Targets Given Fire Control System Failure[a]	N/A	N/A	○ ■	○ ■
Engage Targets Using the GAS	N/A	◒ ⬓	● ⬓	N/A
Engage Targets in Emergency Mode	N/A	N/A	● ■	N/A
Engage Targets in Manual Mode	N/A	N/A	● ⬓	N/A
Engage Targets from the TC Position	N/A	N/A	● ■	◒ ■
Assess Results of Engagement	◒ ⬓		● ⬓	◒ ■

[a] Includes the following failures: ineffective LRF, multiple returns from LRF, loss of GPS symbology, crosswind sensor failure, cant sensor failure, lead angle sensor failure, GPS failure, and GPS/TIS failure.

● All elements (100%) may be performed on the device.
◒ Most elements ($\geq$ 50%) may be performed on the device.
○ Some elements (< 50%) may be performed on the device.
No Symbol No elements may be performed on the device.
■ None of the elements (0%) that may be performed are subject to reduced fidelity.
⬓ Some of the elements ($\leq$ 50%) that may be performed are subject to reduced fidelity.
□ Most of the elements (> 50%) that may be performed are subject to reduced fidelity.
N/A Device does not simulate key conditions required to perform activity.

Figure 5-2. Summary of gunner activities supported by gunnery training devices.

TANK COMMANDER ACTIVITIES	TRAINING DEVICES U-COFT		SIMNET	
Prepare Stations for Operation (PREOPS)	◒	⬓	◒	□
Perform Prepare-to-Fire (PREFIRE) Checks	◒	□	◒	⬓
Acquire Target(s)	◒	□	◒	□
Engage Single Target from the Offense Using Precision Gunnery	◒	⬓	●	⬓
Engage Single Target from the Defense Using Precison Gunnery	●	■	●	■
Adjust Fire	◒	⬓	●	⬓
Engage a Single Target with the Coax	●	⬓	N/A	
Engage Multiple Targets with the Main Gun	●	⬓	●	■
Engage Targets with the Cal .50	◒	⬓	N/A	
Engage Targets Using Battlesight Gunnery	●	⬓	●	⬓
Engage Targets Given Fire Control System Failure[a]	◒	⬓	○	⬓
Engage Targets Using the GAS	◒	■	N/A	
Engage Targets in Emergency Mode	●	■	N/A	
Engage Targets in Manual Mode	●	⬓	N/A	
Engage Target from the TC Position	●	⬓	●	⬓
Assess Results of Engagement	◒	⬓	◒	⬓

[a] Includes the following failures: ineffective LRF, multiple returns from LRF, loss of GPS symbology, crosswind sensor failure, cant sensor failure, lead angle sensor failure, GPS failure, and GPS/TIS failure.

● All elements (100%) may be performed on the device.

◒ Most elements ($\geq$ 50%) may be performed on the device.

○ Some elements (< 50%) may be performed on the device.

No Symbol No elements may be performed on the device.

■ None of the elements (0%) that may be performed are subject to reduced fidelity.

□ Some of the elements ($\leq$ 50%) that may be performed are subject to reduced fidelity.

⬓ Most of the elements (> 50%) that may be performed are subject to reduced fidelity.

N/A Device does not simulate key conditions required to perform activity.

Figure 5-3. Summary of tank commander activities supported by gunnery training devices.

LOADER AND DRIVER ACTIVITIES	SIMNET STATION Loader	SIMNET STATION Driver
Prepare Stations for Operation (PREOPS)	○ □	○ □
Perform Prepare-to-Fire (PREFIRE) Checks	◒ □	● ⬓
Acquire Target(s)	◒ ⬓	◒ □
Engage Single Target from the Offense Using Precision Gunnery	◒ □	● ⬓
Engage Single Target from the Defense Using Precision Gunnery	◒ □	● ⬓
Adjust Fire	● □	● □
Engage a Single Target with the Coax	N/A	N/A
Assess Results of Engagement	○ ■	● ■

[a] Includes the following failures: ineffective LRF, multiple returns from LRF, loss of GPS symbology, crosswind sensor failure, cant sensor failure, lead angle sensor failure, GPS failure, and GPS/TIS failure.

●	All elements (100 %) may be performed on the device.
◒	Most elements ($\geq$ 50%) may be performed on the device.
○	*Some elements (< 50%) may be performed* on the device.
No Symbol	No elements may be performed on the device.
■	None of the elements (0%) that may be performed are subject to reduced fidelity.
⬓	Some of the elements ($\leq$ 50%) that may be performed are subject to reduced fidelity.
□	Most of the elements (> 50%) that may be performed are subject to reduced fidelity.
N/A	Device does not simulate key conditions required to perform activity.

Figure 5-4. Summary of loader and driver activities supported by SIMNET device.

2. Despite its avowed purpose to train tactical skills, SIMNET can support training of much of the gunnery domain. In terms of gunnery conditions, SIMNET provides a simulation of the mission requirement gunnery parameters (e.g., fire control, movement formation) that are not supported at all by the other simulators. In terms of actions, SIMNET provides a sufficient simulation of many crew gunnery activities, and it is the <u>only</u> computer-based simulator to provide practice on driver and loader activities.

3. The low-cost gunnery devices (VIGS and TopGun) provide adequate simulations of the conditions and actions related to precision gunnery from a stationary tank. While this activity is but a small part of the gunnery domain, precision gunnery skills are regarded as prerequisite to many of the other aspects of gunnery.

The tables point to some general device limitations as well. It should be noted that many of these negative comments represent "old news" simply restating what may be obvious to those who work with these devices. Other comments are not necessarily indictments of devices because they may not have been designed to train objectives within the presently defined gunnery domain. In other words, the following device limitations may be interpreted as deficiencies only with respect to our proposed training program.

1. VIGS, TopGun, and SIMNET allow crewmembers to perform few if any activities related to secondary gunnery functions (PREOPS and PREFIRE procedures). Furthermore, although U-COFT does provide some simulation of these activities, it also has potential sources for negative transfer. These sources of negative transfer are discussed in the next section.

2. In general, fidelity measures for all devices are low with respect to target acquisition activities. These poor ratings are partly due to the fact that no simulator simulates open hatch viewing. <u>Tank Combat Tables</u> (FM 17-12-1) states that "during buttoned-up [closed hatch] operations, the tank crew's ability to acquire targets is reduced by at least 50 percent..." (p. 3-3). Therefore, the preferred mode for target acquisition is not simulated by any of the devices.

3. Whereas many of elements of driving and loading are simulated by SIMNET, a substantial portion must be performed under reduced fidelity. In that regard, Bessemer (1986) evaluated SIMNET with respect to driver activities. He concluded that whereas fidelity of SIMNET driving could be sufficient to support tactical movement and manuever, there were significant fidelity problems to invalidate its use for training and sustaining basic fine driver control skills. Similar fidelity limitations affect SIMNET's simulation of loading. For instance, the act of physically removing a round from the ready rack and loading it into the main gun tube is simulated by a series of button pushes. We conclude, therefore, that SIMNET is not appropriate for initial training of either loader or driver skills.

4. As indicated by Figure 5-1 and the not applicable (N/A) symbols in Figures 5-2 to 5-4, some important parameters of the gunnery domain are not simulated by the devices:

- VIGS and TopGun do not simulate owntank movement. Therefore, they cannot provide training in engaging targets from a moving tank, an important offensive gunnery technique.

- VIGS, TopGun, and SIMNET provide little if any practice on degraded mode gunnery techniques. U-COFT simulates some of the important degraded gunnery techniques such as battlesight gunnery, engaging targets using the gunner's auxiliary sight (GAS), and engaging targets in emergency and manual modes. However, even U-COFT fails to provide simulation of the following fire control system failures: loss of GPS symbology, crosswind sensor failure, cant sensor failure, and lead angle sensor failure.

- Not all weapon systems are simulated. The M240 coaxial machine gun is not represented by TopGun and SIMNET, and Cal .50 machine gun is not represented on VIGS, TopGun, and SIMNET. These deficits severely restrict the types of engagements that can be trained on the devices.

Specific Sources of Negative Transfer and Correlations. As explained above, the analysis of gunnery actions identified activity elements in which positive transfer or correlation between device and tank was not expected (evaluation question d in the previous section). In some cases, positive relations were not predicted because the device is so unlike the actual equipment. The focus of this section, however, is on a subset of those instances of nontransfer for which there are reasons to predict negative transfer and/or negative correlations. We realize that the effects of any negative transfer or correlation source may be mitigated by appropriate instruction or control of practice events. Thus, the following problems must be regarded as potential sources of negative transfer or correlation.

We begin this discussion with negative sources of transfer or correlation that are general in that they apply to more than one device:

1. U-COFT and VIGS exercises start with some sort of preview that includes a description of the to-be-engaged target(s) and the conditions under which the engagement is to be conducted.[7] These previews encourage the student to preset switches on the Fire Control Panel according to the exercise conditions. Students could learn to depend on this sort of preview information, which is certainly not available in a tactical gunnery situation. Most importantly, the presence of a preview encourages the student to arm the main gun/coax and the laser range finder before receiving a fire command from the TC. The unsafe habit of presetting

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[7]Target previews on the M1 VIGS are only presented on the Perceptronics demonstration videodisc, not on the ARI experimental thermal videodisc.

these switches in the tank can lead to accidental firings of the laser or weapon resulting in injury or death.

2. VIGS, TopGun, and U-COFT do not simulate the loader's station, and none of the devices (including SIMNET) simulate main gun recoil. Thus, they do not provide the negative consequences associated with firing the gun too quickly. Boldovici (in press) speculated that this specific fidelity deficit plus scoring systems that place a premium on quick responding result in gunnery training that overemphasizes speed at the expense of accuracy or safety considerations. Improper loading or firing before the loader's "UP" announcement can result in serious injury to the loader.

3. The three devices that employ computer-generated imagery (TopGun, U-COFT, and SIMNET) do not provide appropriate texture gradient and aerial perspective cues for perception of depth.[8] The result is that targets appear closer causing ranges to be underestimated. These misleading cues are a potential negative correlation source because experts would be more likely to use these depth cues than novices. Anecdotal reports indicate that experienced crewmen can quickly adjust to the range distortions, apparently ignoring these cues and attending to other monocular depth perception cues that are not distorted by computer-generated displays: apparent size, interposition, and movement perspective.[9]

4. All devices present a limited array of targets that are easily distinguishable. The actual battlefield will be filled with a variety of friendly and threat targets that are easily confused, e.g., Soviet T72 and French AMX tanks. Further, devices present full as opposed to partial target profiles, so that students receive no practice at identifying targets with incomplete information. Consequently, crewmen may fail to develop critical skills needed to identify targets under battlefield conditions.

5. VIGS and SIMNET do not simulate the operation of the lead sensor system. This limitation may result in the gunner acquiring inappropriate behaviors related to tracking moving targets and tracking stationary targets from a moving tank. For one, the student may fail to learn to dump the lead solution when the target reverses direction or when moving

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[8]Texture gradient refers to the changes in the perceived density of detail that varies inversely with distance. Aerial perspective, on the other hand, refers to systematic changes in color as a function of distance, i.e., distant objects are less saturated than close ones and tend to take on the color of ambient light.

[9]Apparent size refers to the perception of distant objects as smaller than closer ones that are equal in physical size. Interposition is the perceptual phenomenon where objects in the foreground block objects in the background from view. Movement perspective is experienced when distant objects appear to displace more slowly than close objects when the objects move or when the observer changes perspective.

to a different target. Also, he may not learn to track targets for required period of time prior to firing. Finally, he may learn to ambush targets (i.e., fire whenever the moving target crosses the reticle aiming point) without having input the correct lead. In this regard, Kraemer and Bessemer (1987) provided evidence of negative transfer from SIMNET training to performance in the Canadian Army Trophy (CAT) competition resulting from this source.

The following negative sources of transfer and correlation apply to certain individual devices:

1. SIMNET color codes targets to distinguish friendly from threat vehicles (friend = tan, threat = green). This extra information in the display makes the process of identifying friend, foe, or neutral targets (IFFN) trivially easy to perform. However, the student may not learn to make the IFFN determination on the basis of target identification as required in the battlefield. Such an effect is analogous to the "crutch" effect cited in the experimental learning literature (Bilodeau, 1952, cited in Boldovici, 1979). To demonstrate a crutch effect, an experimental group is presented some extra informational feedback that aids task performance. When transferred to the same task but without such extra feedback, their performance is inferior with respect to a control group who learned to perform the task in absence of the extra information. Although originally defined with respect to informational feedback, Boldovici (1979) extended the concept of a performance "crutch" to other salient stimuli that control task performance.

2. TopGun color codes targets with respect to engagement priority (red = most dangerous, yellow = dangerous, blue = least dangerous) in the Wide Field of View area of the display. Because these extra cues are not available in tactical gunnery, the potential exists for a crutch effect as described above. Specifically, the gunner may not learn to classify targets as he would on the battlefield, i.e, on the basis of target behavior, lethality, and range.

3. As performed on U-COFT, the PREFIRE activities--particularly those related to boresighting--are substantially different from those outlined in FM 17-12-1. Consequently, the student may learn incorrect and/or suboptimal boresighting procedures. For instance, U-COFT boresighting requires the gunner to take only one set of boresight readings that are directly input into the ballistic computer. M1 procedures (FM 17-12-1) call for the gunner to take two readings, compute an average, and input the average into the ballistic computer. The problems associated with boresighting in the U-COFT are detailed by Morrison (1987).

4. The thermal image in the U-COFT is a simple translation of the day channel image. Therefore, it does not provide any extra information than the actual M1 sight provides. This extra information includes signatures such as hot gun tubes or tracks that can be used to acquire targets but would otherwise be unobservable through the day channel. Research indicates that alternating viewing between thermal and optical

sights increases the probability of target detection (Kottas & Bessemer, 1983) Indeed, anecdotal reports from U-COFT instructors indicate that experienced gunners often search day scenes with both channels in the U-COFT. However, after it becomes clear to the student that there is no additional information in the U-COFT thermal sight, this appropriate alternating behavior occurs less frequently.

5. To score a hit on the prototype M1 VIGS, the reticle must be on the target at the time of impact. The result is that, unlike the actual equipment, control handle inputs can affect the fall of the round after the shot has been fired. The student gunner may acquire both good and bad habits as a result of this device logic. On the positive side, the student learns the appropriate behavior of continuing to track after firing, a strategy that increases the probability of observing round effects and achieving a second round hit. Unfortunately, he may also learn to fire quickly without a correct sight picture, and then to adjust the reticle/target relationship as the round is in flight. The latter behavior is clearly inappropriate for tank gunnery.

Conclusions

In this section, we summarize the results of the device evaluation by presenting suggested short- and long-range solutions to some of the more serious fidelity problems. Short-range solutions are changes to the way we use training media and devices. These changes will be incorporated in the proposed training program. Long-range solutions involve extensive software changes or training device development, both of which are beyond the scope of the present project.

Safety-related Problems. Two problems were described which indicated that gunnery devices overemphasize speed of responding to the detriment of safety concerns. The short-range solution is to train instructors to be vigilant in detecting safety-related errors such as presetting fire control switches or firing before the loader's UP announcement. Unfortunately, the low-cost trainers (VIGS and TopGun) are designed to be used with little or no instructor intervention. The longer term, and perhaps more satisfactory, solution is to upgrade device capabilities to detect such errors and to penalize students accordingly.

Secondary Functions. Gunnery devices are not now capable of training the secondary functions of PREOPS and PREFIRE procedures. One solution is to develop a procedures trainer for those purposes. However, secondary function training can be accomplished on the actual tank without incurring costs related to going to the range and firing live ammunition. For instance, training on these tasks can be accomplished in areas such as the motor pool. In summary, the tank itself is still probably the best medium for training these tasks.

Loader and Driver Skills. At the present time, there are no devices that address the initial acquisition of driver and loader skills related to tank gunnery. However, tank driver trainers (TDTs) are proposed to be

implemented in institutional training for both the M60- and M1-series tanks in the near future (U.S. Army Armor School, 1987). Designed for initial training on driving skills, the TDTs will consist of a realistic driving compartment that presents real time visual and motion cues associated with standard, degraded, and emergency conditions. There are no corresponding plans to produce a loader trainer. One could argue that loading tasks involve primarily gross motor skills that would not be cost effectively trained by a computer-based device. On the other hand, loading a round on a moving tank may require a certain degree of fine motor skill. Research should be performed to more precisely define the performance requirements of loading in order to determine the need for a loader trainer.

Target Acquisition. Target acquisition training is not well supported by the present devices. The short-term solution is to design a field-based target acquisition course that reduces the use of operational equipment and increases the student's opportunities to practice the decisions required in target acquisition. A long-term solution would be to design and build a target acquisition part-task trainer that allows practice on these activities without going to the field. The training objectives for the part-task trainer could address some or all of the specific deficiencies noted in this report: (a) range estimation, (b) target identification, (c) target classification, (d) thermal vs. optical channels viewing, and (d) open- vs. closed-hatch viewing. The trainer would require high fidelity with respect to the visual display. However, because the objective is to practice decision-making skills related to target acquisition, response/control fidelity could be only minimal. For instance, the output decisions, such as target engagement, could be indicated by a button push or the like. A possible medium for this trainer could be an intelligent (i.e., computer-controlled) videodisc system with high resolution video.

Degraded Mode Gunnery. Although the U-COFT addresses nonprecision gunnery, it does not provide practice on every aspect of degraded mode gunnery. This may not be critical, however, as our domain indicates that, other than battlesight and GAS gunnery, degraded mode gunnery consists of relatively few unique actions that must be practiced. The difficulty in employing degraded techniques is, therefore, not in the performance of those techniques but in the recognition of the conditions under which they are used. In other words, performance problems related to degraded mode gunnery reflect knowledge rather than skill deficiencies. In that regard, ARI and the Training Technology Field Activity (TTFA) have developed courseware on degraded mode gunnery for implementation on the Hand-Held Tutor (HHT). The HHT is a low-cost, electronic device for providing drill and practice on selected Army technical training topics. Hoffman (1987) has noted some inaccuracies in the HHT courseware. Nevertheless, the HHT is a useful adjunct device to promote acquisition of knowledges related to degraded mode gunnery.

Instructional Features

Instructional features are generally defined as hardware and software capabilities that support the process of instruction in computer-based training devices. At least seven research reports have attempted to inventory and define instructional features (Caro, Pohlman, & Isley, 1979; General Electric, 1983; Logicon, Inc., 1985; Hughes, 1979; Pozella, 1983; Semple, Cotton, & Sullivan, 1981; and Sticha et al., 1986). Appendix H summarizes this literature by describing each feature in terms of its function, its training purpose, and other references in the research literature. Two generalizations may be drawn from this literature. First, many of the features are specifically oriented to flight training applications, e.g., crash override. This observation reflects the fact that the initial research on instructional features was performed in the context of flight training. Nevertheless, there is one review (General Electric, 1983) that is in fact oriented to development of an armor training device--the Institutional Conduct of Fire Trainer (I-COFT). Second, there are differences among these research reports in the contents of their inventories. Appendix H indicates the relative agreement by listing features in order of the number of associated references. The features with more references are more general in function (i.e., less dependent on the nature of training), whereas features with fewer references were more idiosyncratic in nature (i.e., relevant to a particular training application). We expected that armor gunnery devices would employ some of the conventional, general purpose instructional features as well as those oriented specifically to armor gunnery applications.

Some of the instructional features listed in Appendix H are specifically designed to measure performance rather than to facilitate training per se. Such features include automated performance measurement, hardcopy/printout, and data storage/analysis. These capabilities are viewed as instructional features because they off-load performance measurement as an instructor duty. However, the focus of the present section is on instructional features that facilitate individual skill acquisition or the process of training on the device. Performance measurement capabilities are examined in detail in Chapter 6.

Much of the research on the effectiveness of instructional features has been performed by Hughes and his associates in the context of flight simulation. In reviewing this literature, Sticha et al. (1986) noted results from three studies. Hughes, Hannaman, and Jones (1979) showed that use of automated demonstration and record/replay features was shown to be less beneficial than a single practice trial. Hughes, Lintern, Wightman, and Brooks (1981) demonstrated that use of freeze and reset features did not significantly increase performance. In contrast to the two previously cited studies, Bailey, Hughes, and Jones (1980) found significant performance improvement as a result of using the initial conditions feature to provide backward chaining schedule for training a 30-degree dive bomb task. However, Sticha et al. cautioned the reader to avoid implicitly accepting the null hypothesis:

> It would be inappropriate to conclude from these experiments that the initial conditions instructional feature is effective and that the automated simulator demonstration, record/replay, freeze, and reposition instructional features are not. It is quite likely that the training efficiency of an instructional feature is largely dependent upon the manner in which it is employed. Thus, a more appropriate interpretation of these data emphasizes the positive results of Bailey et al. (1980): Their experiment showed that the initial conditions instructional feature can provide significant training benefits if combined with an effective training technique such as backward chaining. (p. 64)

Although the literature on instructional features is not extensive, this review indicates that features can be effective given an appropriate application. Accordingly, our analysis of instructional features not only identified the features that are incorporated on current devices but also specified how they may be used to determine their effectiveness.

Evaluation of Instructional Features

As a first step, we identified the instructional features available on each device. The list of instructional features in Appendix H was used as a guide in determining device capabilities. The technical literature on the devices was also helpful in determining device capabilities. However, the device literature often used unique terms to describe device features. To facilitate comparisons across devices, we used more common feature names as given in Appendix H to describe the device functions. As expected, however, examination of the devices revealed special purpose instructional features not in Appendix H. These more idiosyncratic features were given names that were descriptive of their functions. Table 5-1 provides a summary of the armor device instructional features including a short description of how each feature is implemented on particular devices. In all, 17 separate features were identified over all 4 devices. Of the 17, 12 instructional features were found implemented on U-COFT in comparison with 9 on TopGun, 7 on VIGS, and 4 on SIMNET.

Table 5-1 also organizes features into trainer functions that they are intended to support. Similar taxonomic schemes have been used in the literature (e.g., Semple et al., 1981; Logicon, Inc., 1985). This organization was also used to explicate the functions of features and to structure the following comments. Included in the comments are our speculations as to how the feature is or should be used to affect learning.

Table 5-1

Training Features as Implemented on the Gunnery Training Devices

Training Function / Training Feature	Gunnery Training Devices: VIGS	TopGun	U-COFT	SIMNET
Plan Training				
Scenario Control	Selects exercises according to a set of 3 parameters.	Creates and stores exercises according to a set of 8 parameters.	Selects exercises according to a set of 9 parameters.	Creates scenarios according to 11 parameters.
Exercise Sequence Control	Manually sequences selected exercises.	Automatically generates exercise parameters according to two factors: . student proficiency level, and . stage of learning.	Automatically sequences students through a "training matrix" derived from three dimensions of difficulty: .reticle aim, .target acquisition, and .system management.	N/A
Control Practice				
Record/Replay	N/A	Records and replays visual cues from an exercise.[a]	Records and replays visual and aural cues (except for crew communications) from an exercise.	Records missions for replay on Plan View Display (see Remote Graphics Replay).
Freeze/Unfreeze	N/A	Freezes/unfreezes action in present exercise.[a]	Freezes/unfreezes action in present exercise.	N/A
Reset	N/A	Automatically resets to beginning of current stage if player is killed but has remaining "tanks."[b] (See Kill Override)	Restarts (repeats) any exercise that has been selected.	N/A
Kill Override	N/A	Allows player three "tanks" (lives); if any remain, player is reset after being killed.	N/A	Reconsititues tank at point of kill or any other location in the data base specified by the controller.

(table continues)

Training Function Training Feature	Gunnery Training Devices VIGS	TopGun	U-COFT	SIMNET
Administer/Monitor Training				
Remote Instructor/ Operator Station (IOS)	N/A	N/A	Controls operation of U-COFT, provides variety of on-line performance data, and provides continuous viewing of sight pictures.	N/A
Procedures Monitoring	N/A	N/A	System Set-Up specifies which switches should be monitored and any switch position errors that occur at the beginning of the exercise.	N/A
Computer-Managed Instruction	N/A	N/A	Keeps track of individual, crew, and unit progress through the training matrix.	N/A
Briefing Utilities	N/A	N/A	Provides a written briefing on the upcoming exercise for the instructor to deliver to the student.	
Adjust Gunnery Parameters				
Ammunition Load	Varies the maximum number of rounds that may be fired in a single engagement.	Varies initial tank ammunition load that is available for the entire game.	N/A	Varies the number of main gun ammo rounds available for the simulated mission.[c]
Variable Loading Interval	Varies the interval from the fire command to UP announcement.	Varies the interval from the fire command to the UP announcement	N/A	N/A

(table continues)

Training Function	Gunnery Training Devices			
Training Feature	VIGS	TopGun	U-COFT	SIMNET
Kill Zone	Varies the criteria for hitting a target from 5% to 300% of the target profile.	Varies the criteria for hitting a target up to 100% of target profile.	N/A	N/A
Reticle Misalignment	Misaligns aiming point with fall of round causing first-round miss.	N/A	N/A	N/A
Simulate Events				
Automated Crewmembers	Simulated TC provides fire commands and LDR announces UP.	Simulated TC provides fire command and LDR announces UP. TC can also override GNR's controls to "slew" turret toward most dangerous target.	Simulated LDR announces up and DVR responds to MOVE OUT and STOP commands.	N/A
Malfunction Selection	N/A	Can simulate "GPS out" condition by presenting GAS reticle.	Selects exercises containing desired malfunctions.[d]	N/A
Ammo Select/ Reload Keys	N/A	N/A	Initiates simulation of loading/reloading round including aural cues and ballistic characteristics of round when fired.	N/A

Note. The symbol N/A indicates that the instructional feature is not available on the device.

[a]This feature is only available on TopGun models equipped with the TC station.

[b]TopGun models equipped with TC stations will allow the instruction/TC to reset the game to the beginning of the current stage or to the beginning of the next stage.

[c]Other rounds may be received during mission from resupply vehicle. Ammunition load is one of the conditions required to specify a scenario.

[d]Malfunction Selection may be regarded as a subfunction of Scenario Control rather than a separate training feature because malfunctions may be accessed only through selection of appropriate exercises.

Prepare Training. Two of the features provide the instructor the ability to prepare meaningful exercises on the training device. The two features address the creation and sequencing of training exercises.

1. Scenario control. There are two fundamentally different versions of scenario control as implemented on the gunnery training devices. In the first version, as implemented on VIGS and U-COFT, the instructor selects features from a finite set of "canned" exercises according to a set of parameters. In the second, as implemented on TopGun and SIMNET, the instructor can "create" virtually an unlimited number of scenarios from a similar but longer set of parameters. Whereas the latter version of scenario control is capable of presenting a wider variety of exercises, we suspect the former version is easier to use. However, TopGun has the capability of storing parameters, making it easy to recreate a complicated exercise. SIMNET has no such corresponding feature.

2. Exercise sequence control. The second feature in this category allows the instructor to select and sequence preprogrammed exercises according to some scheme of instruction. VIGS requires the instructor to manually sequence selected exercises prior to a training session, whereas TopGun and U-COFT automatically sequence exercises. Although the automatic feature would appear more labor-saving than the manual version, the sequencing method implemented on TopGun and U-COFT may not be valid. The sequencing algorithms are not based on any discernable instructional theory or practice; rather they appear to be based on some implicit notion of task difficulty. Finally, because SIMNET has no ability to store initial exercise conditions, it has no provision for automatically or manually sequencing exercises.

Control Practice. In addition to setting up a series of exercises, the instructor also needs on-line control of practice in order to facilitate learning. The following features allow the instructor to control certain practice events designed to speed learning.

1. Record/replay. To learn any task, a student must have some knowledge of his task performance. One potentially effective method for providing at least some of that feedback is through a replay of stimulus events that occurred during performance of an exercise. Whereas there are reasons to doubt the effectiveness of passive viewing, replay with expert interpretation is potentially a powerful pedagogical technique. TopGun and U-COFT both provide record/replay features whereas VIGS does not. SIMNET provides a form of replay through its Plan View display. This display provides a top-down view of all or a subset of simulated vehicles in the data base including text information on each vehicle (e.g., location, speed, orientation). Unfortunately, this display is oriented more towards tactical training than towards gunnery training.

2. Freeze/reset. A common approach to training difficult tasks is to isolate the difficult task elements and provide repetitive practice on those particular elements. The freeze/unfreeze and reset features make it possible to provide this potentially effective form of practice. The freeze feature can also be used to interrupt training to provide coaching

comments. The effectiveness of this application would depend on the detrimental effects of interrupting training vs. the quality of the coaching comments. Freeze/unfreeze and reset features are implemented on TopGun and U-COFT, whereas they are not represented on VIGS and SIMNET.

3. Kill override. Frequent simulated kills of the student's tank can interrupt the "flow" of training. A kill override feature can be used to eliminate or, at least, to minimize such interruptions. Kill override should be used in the early stages of learning where the probability of a kill is highest, but the student should experience more realistic mortality effects as he gains experience. This feature is notably absent in U-COFT, wherein exercises end whenever the owntank is killed. On the other hand, kill override is somewhat irrelevant to VIGS where owntanks cannot be killed.

Administer and Monitor Training. The following instructional features, all implemented on U-COFT, are designed to aid the instructor in administering and monitoring training.

1. Remote instructor/operator station and procedures monitoring. Two features aid the instructor in monitoring the process of instruction. The remote instructor/operator station allows the instructor to closely monitor U-COFT performance while not being in the student compartment with him. There is less need for this feature in VIGS and TopGun where student performance is more observable. On the other hand, SIMNET would greatly benefit from these features because student's perform within compartments where direct observation is impossible. The procedures monitoring function (called "system set-up" in the U-COFT manuals) allows the instructor to monitor switch positions via the I/O station.

2. Computer-managed instruction. U-COFT automatically maintains records of crew and unit performance and makes it accessible to training managers. The problem with this feature is that performance information is provided with reference to the three-dimensional matrix model of training progression. If the trainer uses some other instructional model, the records are not particularly useful.

3. Briefing utilities. The U-COFT presents via the instructor/operator station display a briefing to be read to the student concerning the upcoming exercise. One problem with this briefing is that it is, in some cases, too informative. For instance, the briefing not only informs the student as to the nature of a simulated malfunction without his having to test for it but the correct course of action as well.

Adjust Gunnery Parameters. There are a few special-purpose features designed to adjust parameters of tank gunnery. These idiosyncratic features were given names that are descriptive of their functions.

1. Ammunition load. Except for the U-COFT, the simulators have the capability to vary the number of rounds that are available to the gunner. By systematically varying the load, this feature allows the instructor to train the gunner and tank commander to be more aware of their ammo status

and to adjust their behavior accordingly. Training should be designed to exploit this feature.

2. Variable loading interval. VIGS and TopGun have the capability to vary the interval from the fire command to the loader's UP announcement. This feature prevents the gunner's timing from becoming too rigid. There are at least two possible ways that this feature can be implemented. One possible strategy is to decrease the loading interval as the student gunner gains skill. This strategy simulates the improvement of loader performance as a function of practice. The second strategy is to vary the loading times according to a random distribution that is representative of loader performance. The latter strategy should train the gunner to adjust to realistic variations in loading times. In either case, until some basic questions about the loading interval's relationship to gunnery training and performance are answered, the appropriate strategy for implementing this instructional feature remains uncertain.

3. Reticle misalignment. The VIGS has the capability of inducing a first round error by misaligning the reticle aiming and target impact points for practicing burst-on-fire adjustment techniques. According to this technique, the gunner compensates for a first-round miss by changing his aim according to the perceived relation between the point of impact and the target. Burst-on-target was the preferred method of fire adjustment for M60A1 tanks. However, with the advent on the advanced fire control system of the M1, the burst-on-target technique was superceded by the reengagement method. According to the reengagement method, the gunner enters a new ballistic solution in the computer and relays the reticle on the target's center of mass. Given reticle misalignment, the gunner could achieve a second round hit using the burst-on-target method but would continue to miss using the reengagement technique. Therefore, this feature is not appropriate for training the newer doctrine of fire adjustment.

Simulate Events. Finally, there are a set of so-called "instructional features" that enable the instructor to simulate some event or events that are relevant to training. Because they relate to the simulation rather than training per se, they are more appropriately viewed as fidelity features even though they are traditionally classified as instructional features. Furthermore, the criteria for effectiveness is not whether or not these features increase the amount or rate of learning, but rather whether or not they are required to simulate task events.

1. Automated crewmembers. If a particular crewmember cannot be available for training, his inputs and outputs must somehow be simulated. For instance, the intention of the low-cost simulators (TopGun and VIGS) is to train gunners apart from other armor crewmen. Thus, input from the tank commander and loader must be simulated. In U-COFT, the tank commander is trained with the gunner; therefore, he does not have to be simulated, but the loader's input and output must be simulated (see below). Finally, SIMNET requires all four crewmen; thus, crewmembers do not have to be automated.

2. Malfunction selection. In the gunnery domain, malfunction selection refers to the capability of simulating degraded gunnery modes. Of the four devices, the U-COFT is the only one to offer practice on a variety of degraded modes. (See previous section for details.) The only other device that simulates a malfunction is TopGun, which can present the GAS reticle to simulate a GPS malfunction.

3. Ammo select/reload. Upon hearing the tank commander's fire command, the U-COFT instructor presses the ammo select or reload button to initiate the simulation of the sound's and time intervals associated with loading the round. Most importantly, the ammo select/reload buttons select the ballistic trajectory simulations associated with the selected ammunition. These keys are not required for the low-cost simulators (VIGS and TopGun) wherein the ammunition to be fired is programmed to match the fire command. Nor is it required in SIMNET where the loader initiates the simulation by pushing the appropriate buttons on the ready rack.

Conclusions

In this section, we summarize the results of the evaluation by describing the usefulness of instructional features to the proposed project. As in the previous section, the discussion is organized around the basic instructor functions that instructional features support.

Prepare Training. The device-based training program will require instructors to select training exercises according to certain parameters. All devices have some capability in this regard, but SIMNET appears more cumbersome to use. The ability to sequence training is less crucial to the project.

Control Practice. In the device-based training program, the instructor should be able to control practice closely in terms of providing feedback and repetitive training. For those functions, U-COFT and TopGun appear to be superior to both SIMNET and VIGS.

Administer and Monitor Training. The training administration features (automated training management and briefing) implemented in the U-COFT have no applicability to the current project. However, the U-COFT's ability to closely monitor gunnery performance is a distinct advantage. The latter capability is discussed more fully in the next section.

Adjust Gunnery Parameters. As discussed earlier, the ammo load and loading interval features offer potential training benefits. Questions remain, however, concerning how these features may be effectively implemented. The device-based training program will not exploit these features until the questions are answered.

CHAPTER 6

IDENTIFICATION AND EVALUATION OF DEVICE FEATURES REQUIRED FOR TESTING

This chapter extends our device evaluations to testing applications. In the first portion of the chapter, a number of testing requirements are discussed and our evaluation questions presented. In the last portion, device evaluations are presented. As with the training evaluations, our conclusions are rational analyses of device capabilities as opposed to empirical data on student performance. In essence, they are hypotheses about what should be valid testing approaches and caveats about uses that may best be avoided until empirical evidence is available.

Device Testing Requirements

In Chapter 4, we discussed a number of issues regarding testing requirements. In that discussion, we focused on issues created by the nature of what was being measured--individual performance in the crew context of M1 tank tactical gunnery. In this chapter, we focus on issues created by the nature of the testing medium.

Technical considerations for assessing individual differences are most often discussed in the context of achievement, aptitude, and personality testing emphasizing psychometric characteristics associated with the reliability and validity of the measurement instrument. Reliability and validity remain important requirements for simulators used to assess performance during the acquisition and sustainment of gunnery skills. Furthermore, with the tremendous and varied potential for measures and scores from sophisticated simulators, it is equally important to consider information utility, including questions about data capture and storage, real-time display of performance information, and flexibility of problem presentation.

Validity

The traditional approach for evaluating the validity of job sample measures of performance has been content validity (Cronbach, 1960; Wernimont & Campbell, 1969). The implicit, underlying assumption is that the performance requirements of the test are equivalent to the performance requirements of the job. For content validity, attention focuses on the extent to which all job requirements are covered by the test and on the methods use to score test performance (Guion, 1977; Hambleton, 1980). For simulators, concern over fidelity creates more uncertainty about the equivalence of performance requirements. Therefore, questions concerning the concurrent or predictive validity of the test are also evoked. Our evaluation, however, is necessarily limited to fidelity, domain coverage,

and scoring procedures because we have very limited performance data on which to base concurrent or predictive validity judgments.

Domain Coverage. The analysis of the M1 gunnery domain was constructed to include every important decision and action in the context of tactical gunnery. No superfluous behaviors were included. Furthermore, the tactical gunnery domain has already been partition into activities and options within those activities. Thus, it is important to make sure that every activity and every element in every activity is learned. This also means that there should be some means of assessing performance to provide appropriate feedback for every element. Furthermore, we have argued in Chapter 4 that it is most appropriate to test integrated chunks of the procedure, such as our activities or objectives. Consequently, it is not appropriate to test chunks that have missing elements. There are three questions about element coverage that much be evaluated in order to determine whether an activity (or an option within an activity) is testable.

1. Does the device present the opportunity to perform each element?

2. Are the element measurement requirements (knowledge, behavior, and/or outcome) automatically recorded for the elements?

3. Can an instructor observe and score the elements in an appropriate measurement mode?

The performance model and the measurement mode specification rules, presented in the previous chapter, prescribe what constitutes appropriate means for assessing each gunnery task element.

A second aspect of domain coverage concerns coverage of the gunnery conditions. This evaluation is described in Chapter 5 and presented in Appendix F. Because of the built-in redundancy between the activity designations and the conditions, evaluation of whether primary conditions (e.g. type of target, equipment status) are presented are implicit in our domain coverage evaluations. Secondary conditions (e.g. NBC conditions, target sector) are evaluated only in Appendix F. For any activity, the more of these secondary conditions that can be represented by a device, the less deficient the evaluation. For example, from the Grafenwöhr data presented in Chapter 3, we know that NBC conditions produce lower gunnery performance. We do not know whether this decrement is the same for all crews. Therefore inferring non-NBC performance from NBC performance may be erroneous. Testing under both conditions is more appropriate.

Element Scoring Criteria. While our prescriptions for measurement mode provide a starting point for evaluating scoring criteria, there is still concern for the relationship between the score and the dimension that underlies the score.

One concern is whether the scale used to quantify performance provides a complete, accurate portrayal of the performance. Inappropriate scales or unnecessary categorizations can distort information about

performance. For example, if a gunner's lay at the time of firing is simply scored as on or off target rather than as lay error, information is lost and the power to discriminate among various levels of performance is reduced. Similarly, scales may be unrecognized combinations of performance elements. "Lay error" may refer to sight picture or the fall of the round. If it refers to fall of the round, it is not a truthful index of gunner's lay, but is contaminated by switch settings, ranging, and perhaps even round-to-round dispersion.

A second problem is the likelihood of correct performance. It is a joint function of simulator design, scoring design, and the nature of the behavior. Although it may be appropriate to cue and shape behavior during training by highlighting correct controls, switches, or perceptual cues, score interpretation must be made in light of such alterations.

Composite Scores. As discussed in Chapter 4, composite scores may be viewed as abstractions expressing the utility of performance for some particular purpose. Two different purposes were identified: (a) utility of expected "real world" outcomes of performance, and (b) utility of the performance trial for skill acquisition. There is no a priori reason to believe that a single composite score, produced by a single utility function, will be appropriate for both uses. Therefore to evaluate any composite score produced by a gunnery simulator, we need to ask a number of questions. Is the purpose of the composite clear, and does its construction (the rules or formulas) support the purpose? If the purpose of a composite is not made explicit, the questions are reversed. What are of the rules underlying the composite, and what use(s) do such rules seems to support? What meaning do the scores have in terms of expected performance in future training? What meaning do the scores have in terms of expected performance in the "real world?"

Reliability

Measurement reliability is a function of individual variability in observed behavior in relation to the variability across individuals. The more consistent each individual's scores in comparison to the variance across persons, the greater the reliability of the measure. Several fairly distinct factors influence the variability of individual scores. The heterogeneity of the domain being measured, the level of skill proficiency, and the resulting stability of performance are inherent features of the task that cannot be directly controlled by testing instrument design. However, the extent to which a device supports selection and repetition of engagement sequences to provide multiple observations of performance is an important feature for overcoming inherent performance variability. Other factors are more closely associated with device design. These include measurement instrument characteristics, including equivalence between different devices of the same type, precision of the scoring criteria, and the extent to which judgments are eliminated in the measurement process.

Performance Stability. Apart from any device or testing medium considerations, reliability is directly related to variability in performance over repetitions of the same problem. Particularly in the early stages of skill acquisition, performance is not perfectly correlated from one repetition to the next (Jones, Kennedy, & Bittner, 1981). The person is changing and a plot of performance scores is apt to be a jagged, but rising curve. The trend in the curve is only apparent from visual smoothing of the peaks and valleys. Depending on the amplitude of the peaks and valleys, no one point is very descriptive of such a curve. Likewise, depending on the extremes of trial to trial variation, no one measurement is very descriptive of an individual's true performance ability. Therefore, repetition of measurement through repetition of problem presentation is an important testing characteristic for gunnery simulators.

Measurement Instrument Consistency. Variations in presentation of stimulus or sensitivity of control manipulation across repetitions for the same machine, or between machines can create extraneous variance in performance scores that reduces reliability. For example, all the of devices considered in this report present visual stimuli via a color monitor. Differences between units of the same type in color and contrast adjustment can make targets harder to detect in one unit compared to the other. Computer driven devices of the type being used for M1 gunnery simulation can be also sensitive to adjustments in electrical and mechanical controls (e.g. power control handles, driver's T-bar) linked with computer processing units.

A second aspect of machine consistency is that several of the devices we are examining are either prototypes or in the early stages of production. At times model changes are introduced as new units are delivered. Thus, it cannot be assumed that two apparently similar units of the same type are in fact the same. Thus, in order to evaluate test consistency, we must determine where model changes have created differences among units of the same device.

Elimination of Judgment. A final consideration for reliability is the extent to which the device eliminates the need for a scorer to monitor and evaluate performance. Although automatic scoring has other considerations (see discussion on validity above), certainly eliminating human observation and judgment can increase consistency of measurement (Boldovici, Osborn, & Harris, 1977).

Information Utility

Aside from questions of reliability and validity, performance information must be delivered to gunnery instructors and students in a usable and timely manner.

Real-time Presentation of Performance Information. We have presented tactical gunnery as a complex procedure with few complex motor skill requirements. Diagnostic feedback, therefore, should focus primarily on

whether specific actions took place, with additional information about how well the behavior was executed for some elements. Because there may be up to four persons interacting as a crew in a training session, presentation of information about all elements would be too fast for a single instructor to handle. The most obvious solution is to present information only about omissions and deficiencies in performance. Certainly, consideration needs to be given about when feedback is best given (during execution or before the next trial) with performance information displays timed accordingly.

In addition to amount and timing of information, presentation medium is also an important consideration. Check lists, numbers, pictures, graphs, and narratives are all options for presenting information about performance. Video recordings can present a real-time re-creation of displays viewed by crew members during their performance trial. Our rule of thumb for presentation medium is that information displays should support the data requirements specified by our knowledge, behavior, or outcome measurement mode assignments.

Data Capture and Storage. Computer driven simulators also offer a tremendous capacity to capture and store performance data. Differences inherent in hardware capabilities suggest two kinds of storage and retention intervals. We make a distinction between short- and long-term storage with short-term storage being automatically erased or replaced with the start of each new exercise, and long-term storage retained until erased by an operator. The former can be used for immediate feedback while the later can be used to review performance over several sessions. Long-term storage can also be used for research purposes comparing difference types of persons or intercorrelating performance on different activities or different conditions. Patterns of errors can be detected and perhaps instructions geared toward preventing them can be prepared and tested. Analysis of individual differences in acquisition curves may lead to the capacity to predict terminal performance from performance in early trials. Of course, the usefulness of data capturing and storage is limited by the quality of the data collected as determined by the considerations of reliability and validity.

Adaptive or Flexible Problem Presentation. Testing (as well as training) efficiency is increased to the extent that the testing medium can be directed to the specific objectives of most concern. This is the underlying premise of adaptive testing. These are several levels at which a device may support adaptive testing. At a minimum the device should allow the operator to select parameter conditions in order to select problems of a specific type. At this level, selection is left to the operator guided by whatever testing protocols are available. Alternatively, a device may be pre-programmed to select problems based on each student's performance. An adaptive test, either operator or device controlled, also requires that gunnery problems, defined by variations in condition presentation, be hierarchically ordered to the extent possible. The present report presents hierarchical analyses of gunnery skills but they have not been empirically verified. A more sophisticated device may be designed to branch individual students based on performance, to record

patterns of performance across individuals, and to make adjustments in its branching routine. In the latter case, the device is acting as both a testing device and an automated research tool. None of the devices we reviewed approach this level of sophistication.

Device Evaluation Questions

The above array of evaluation issues includes questions at the behavior level and at the activity or training objective level. At the element level are questions about the presence of the element, availability of automatic scoring, scoring criteria, data presentation medium, and storage. For elements not automatically scored, there is the possibility of scoring by an instructor. At the activity level are issues related to real-time data presentation load and timing, repetition of performance trials, instrument consistency and composite scores. These issues are not independent; however, a concise set of device evaluation questions were derived. They are presented in Table 6-1.

The questions are logically divided into element level and activity level concerns. The first element question, "Can the element be performed?" has already been covered in the evaluation of fidelity presented above. For each of the activity divisions, a determination then is made as to the adequacy of the elements present for representing the activity. This is a subjective judgment based on the number and criticality of missing elements. It may only take a few missing or inadequately represented elements to invalidate testing of a particular activity. If an activity cannot be tested, then testing of individual elements within that activity that are represented is deficient, although occasionally useful. That is, testing isolated elements may determine whether the behavior can be executed, but does not determine whether it will be executed as part of the activity sequence. Testing isolated elements makes sense for high skill behaviors and behaviors with some underlying knowledge (decision) requirement. Target tracking is certainly an element in the M1 tactical gunnery domain that falls into this latter category.

Evaluation of Devices

Procedure

The complete tactical gunnery domain listing of tank commander, gunner, driver and loader elements was converted to separate check lists for each position. For each element, the measurement mode was specified according to the scheme presented in Chapter 4, Tables 4-1 and 4-2. These check lists were used to rate device representation and scoring for each gunnery element. The key to the rating procedure is presented in Table 6-2. Based on these element level ratings and information about device operation and scoring routines, device testing capabilities were

Table 6-1

Evaluation Questions Concerning the Use of Simulators as Testing Devices

Element Level Questions	Activity Level Questions
I. Can the element be performed? If not, the remaining questions are not relevant.	1. Is the domain covered sufficiently to construct a meaningful test? If not, testing is inappropriate and the remaining questions are not relevant.
II. Is the desired measurement mode(s) (K,B, or O) automatically assessed and available for feedback?	2. Is a composite score constructed?
A. Is the scoring criteria appropriate?	a. Is its meaning comprehensible?
B. Is the timing and medium of presentation of the information appropriate?	b. Does it emphasize performance utility or training utility?
C. Is the (element level) data stored for end-of-trial term use?	c. Is the (composite level) data stored for end-of-trial term use?
D. Is the (element level) data stored for long term use?	d. Is the (composite level) data stored for long term use?
III. Can an instructor score the element?	3. Are there instrument inconsistencies?
A. If a behavior measure is needed, can an instructor observe the behavior?	4. Is selection of engagement trials possible?
B. If outcome measure is needed, can an instructor observe the outcome of the behavior either directly or by some remote display?	5. Is repetition of engagement trials possible?
C. For either measure, are there or can there be clear and distinct guidelines for scoring.	

Table 6-2

Ratings Used for Element Level Descriptions of Device Testing Capabilities

Column Heading	Symbol and Interpretation
Measure Required	K - Knowledge assessment B - Behavior assessment O - Outcome assessment , - Used to join optional assessment modes (e.g. K,B = use knowledge or behavior assessment). K&B - Knowledge and behavior both required for diagnostic assessment. (O) - Outcome assessment can be used for proficiency assessment, but has limited diagnostic value.
Element Represented	Y - Performance of the element is expected to mirror performance on the actual equipment. (Y) - Performance of the element is sufficiently different from the actual equipment to reduce expected validity. Partial - Some portion of the performance requirements are not represented. Degraded - degraded stimulus conditions are expected to alter perceptual requirements for the element. N - Element can not be performed sufficiently to score performance.
Automatic Recording Mode	B - Behavior is recorded or scored O - Outcome of the element is recorded or scored T - Elapsed time to element performance is recorded [Note - behaviors or outcomes of elements that are remotely displayed at the time of execution, but not captured for later review are not counted in this column]
Automatic Recording Feedback	Display - Occurrence of the behavior or evaluation of the outcome is printed or displayed on a monitor. Replay - Occurrence of the behavior or representation of the outcome of the element can be watched on a video replay of the performance.
Automatic Recording Storage	L - Behavior or outcome records are "permanent" in the sense that they are not automatically erased/lost when the exercise or training session is over. S - Behavior or outcome records are displayed at the end of the exercise and then erased/lost.
Instructor Scoring	K - Instructor can observe performance or a remote display of performance and score knowledge. B - Instructor can observe performance or a remote display of performance and score behavior. O - Instructor can observe performance or a remote display of performance and score outcome.
Element Testable	Y - Element can be scored either automatically or by an instructor. (Y) - Element can be scored, but reduced validity is expected. N - Element can not be scored.

then rated at the summary level for each of the activities and options within the activities. The key for the summary level descriptions is presented in Table 6-3.

Table 6-3

Ratings Used for Activity Level Descriptions of Device Testing Capabilities

Column Heading		Symbol and Interpretation
Domain Testable	Y -	Elements are sufficiently represented to expect valid information.
	(Y) -	Elements representation is somewhat degraded and information may have marginal validity.
	N -	Element representation is sufficiently degraded to expect little test validity.
Composite Meaningful		Gives a short description of any activity level scores provided.
	Blank -	No composite score is computed for the domain.
Composite Storage		Gives a short description of activity level scores storage for long or short term access.
Selection/Repetition		Describes device capabilities for selecting exercises, e.g. programming a particular sequence of engagements.
Device Inconsistencies		Notes any characteristics that vary among devices and could affect performance scores.

Subjective Ratings

Ratings of "Element Represented" and "Domain Testable" are the two primary evaluation points. Both are subjective. Element represented ratings are based on the fidelity ratings of how closely each element of the simulated task corresponds to the actual task. These ratings were presented in the previous chapter.

An underlying assumption is that element correspondence must be greater for testing than for training. That is, some reduction in element fidelity can occur and still allow some practice of task requirements within an activity. That practice might be expected to transfer to performance on the actual equipment if some time is allotted on the actual equipment to make adjustments. For testing, the difference in performance requirement between the device and the real equipment constitutes an extra component in a device score that has no analogous component in the actual equipment. The rule of thumb is that if there is an extra requirement of the device needed to allow practice, than the validity of testing in that domain is reduced. Our tendency is to be conservative in evaluating device capabilities for providing performance scores that can readily be translated into proficiency on the actual equipment.

General Conclusions

Ratings made to evaluate device testing capabilities at the element level and at the activity level are presented in Appendix I. Summary evaluations of device capabilities for testing are presented in Figures 6-1 to 6-3. Figure 6-1 evaluates each of the four devices for testing gunners. Figure 6-2 evaluates U-COFT and SIMNET for testing tank commanders. Figure 6-3 evaluates SIMNET for testing drivers and loaders.

Despite plans to the contrary, no distinction between proficiency testing and diagnostic testing was made in the evaluations. Our gunnery domain analysis is comprehensive and detailed. As a result, our expectations for diagnostic testing are great. Complete diagnostic testing of performance deficiencies requires that scores be available for every element. For all devices, automated scores were limited in number and tended to be outcome oriented. Outcome measures can suffice for diagnostic applications only for the most simple elements where the procedure is strictly linear and there are no skilled behaviors (Type 1 elements as described in Chapter 4). Thus, diagnostic testing with any of the devices would require instructor support to provide element level evaluations. Given reliance on instructor support, the key evaluation criteria for both proficiency testing and diagnostic testing is sufficient domain coverage. Furthermore, from the discussion in Chapter 4, near perfect presentation of the elements is required to obtain complete diagnostic information or to obtain a valid domain score. Thus, our device evaluations for testing were influenced most heavily by element fidelity and domain coverage. The ratings that appear in Figures 6-1 to 6-3 indicate our assessment of the capability of a device to provide a valid proficiency and/or diagnostic assessment of skills within each division of the domain on the assumption that assessment will be supported by an instructor participating in the scoring process.

Given the emphasis on device fidelity, it is not surprising that our conclusions for testing capabilities parallel our conclusion for training capabilities. That is, VIGS and TopGun provide gunner marksmanship training only, so their testing potential is limited to gunnery domain Activities 4 through 7. Even for these activities, their coverage is

DOMAIN OF ARMOR GUNNERY CREW BEHAVIORS	VIGS	TOPGUN	UCOFT	SIMNET
ACTIVITY 1. PREPARE STATIONS FOR OPERATION (PREOPS)	○	○	○	○
ACTIVITY 2. PERFORM PREPARE-TO-FIRE (PRE-FIRE) CHECKS)	○	○	○	○
Option 2.1. Prepare for Offense	○	○	○	○
Option 2.2. Prepare for Defense	○	○	○	○
ACTIVITY 3. ACQUIRE TARGET(S)	○	○	○	○
Part 3.1. Search for Target(s)	○	○	○	○
Option 3.1.1. Search Open Hatch - Day	○	○	○	○
Option 3.1.2. Search Closed Hatch - Day	◒	◒	◒	◒
Option 3.1.3. Search at Night	◒	◒	◒	○
Part 3.2. Detect/Locate/Identify Target(s)	○	○	◒	◒
Part 3.3. Evaluate Situation	N/A	N/A	N/A	N/A
ACTIVITY 4. ENGAGE SINGLE TARGET WITH THE MAIN GUN	◒	◒	●	◒
Option 4.1. Engage Single Target from the Offense Using Precision Gunnery	○	○	●	◒
Option 4.2. Engage Single Target from the Defense Using Precision Gunnery	◒	◒	●	◒
Option 4.3. GNR Cannot Identify Announced Target	○	○	●	◒
Option 4.4. Engage Targets Using TIS	◒	◒	◒	○

● Device expected to have utility for testing.

◒ Device expected to have only marginal utility for testing.

○ Device not recommended for testing.

Figure 6-1. Evaluation of device utility for testing gunner performance.

DOMAIN OF ARMOR GUNNERY CREW BEHAVIORS	VIGS	TOPGUN	UCOFT	SIMNET
ACTIVITY 5. ADJUST FIRE	◒	◒	●	◒
Option 5.1. Use Reengage Technique	◒	◒	●	◒
Option 5.2. Use Standard Adjustment	○	○	●	○
Option 5.3. Use TC Adjustment	○	○	●	◒
ACTIVITY 6. ENGAGE A SINGLE TARGET WITH THE COAX	●	○	●	○
ACTIVITY 7. ENGAGE MULTIPLE TARGETS WITH THE MAIN GUN	◒	◒	◒	◒
ACTIVITY 8. ENGAGE TARGETS WITH THE CAL .50	○	○	●	○
Option 8.1. Simultaneous Targets	○	○	●	○
Option 8.2. Cal .50 Targets	○	○	●	○
ACTIVITY 9. ENGAGE TARGET USING DEGRADED GUNNERY *TECHNIQUES*	○	○	◒	○
Option 9.1. Engage Target Using Battlesight Gunnery	◒	○	●	●
Option 9.2. Engage Target Given Ineffective LRF	○	○	●	○
Option 9.3. Engage Target Given Multiple Returns from LRF	○	○	●	●
Option 9.4. Engage Target Given No Range Display	○	○	◒	○
Option 9.5. Engage Target Crosswind Sensor Failure	○	○	◒	○
Option 9.6. Engage Target Given Cant Sensor Failure	○	○	◒	○
Option 9.7. Engage Target Given Lead Sensor Failure	○	○	○	○
Option 9.8. Engage Target Given GPS Failure (Day Channel)	○	○	○	○

● Device expected to have utility for testing.

◒ Device expected to have only maginal utility for testing.

○ Device not recommended for testing.

Figure 6-1. Evaluation of device utility for testing gunner performance (cont'd).

DOMAIN OF ARMOR GUNNERY CREW BEHAVIORS	VIGS	TOPGUN	UCOFT	SIMNET
Option 9.9. Engage Target Given GPS/TIS Failure	○	○	●	○
Option 9.10. Engage Target Using GAS	○	◒	●	○
Option 9.11. Engage Target in Emergency Mode	○	○	●	○
Option 9.12. Engage Target in Manual Mode	○	○	●	○
ACTIVITY 10. ENGAGE TARGET(S) FROM THE TC POSITION	**N/A**	**N/A**	**N/A**	**N/A**
ACTIVITY 11. ASSESS RESULTS OF ENGAGEMENT	○	○	○	◒

● Device expected to have utility for testing.

◒ Device expected to have only maginal utility for testing.

○ Device not recommended for testing.

Figure 6-1. Evaluation of device utility for testing gunner performance (cont'd).

DOMAIN OF ARMOR GUNNERY CREW BEHAVIORS	UCOFT	SIMNET
ACTIVITY 1. PREPARE STATIONS FOR OPERATION (PREOPS)	○	○
ACTIVITY 2. PERFORM PREPARE-TO-FIRE (PRE-FIRE) CHECKS	○	◒
Option 2.1. Prepare for Offense	○	◒
Option 2.2. Prepare for Defense	○	◒
ACTIVITY 3. ACQUIRE TARGETS	◒	◒
Part 3.1. Search for Target(s)	○	○
Option 3.1.1. Search Open Hatch - Day	○	○
Option 3.1.2. Search Closed Hatch - Day	○	○
Option 3.1.3. Search at Night	○	○
Part 3.2. Detect/Locate/Identify Target(s)	◒	◒
Part 3.3. Evaluate Situation	◒	◒
ACTIVITY 4. ENGAGE SINGLE TARGET WITH THE MAIN GUN	●	●
Option 4.1. Engage Single Target from the Offense Using Precision Gunnery	●	●
Option 4.2. Engage Single target from the Defense Using Precision Gunnery	●	●
Option 4.3. GNR Cannot Identify Announced Target	●	●
Option 4.4. Engage Targets Using TIS	●	○

● Device expected to have utility for testing.

◒ Device expected to have only maginal utilization for testing.

○ Device not recommended for testing.

Figure 6-2. Evaluation of device utility for testing tank commander performance.

DOMAIN OF ARMOR GUNNERY CREW BEHAVIORS	UCOFT	SIMNET
ACTIVITY 5. ADJUST FIRE	●	●
Option 5.1. Use Reengage Technique	●	●
Option 5.2. Use Standard Adjustment	N/A	N/A
Option 5.3. Use TC Adjustment	●	●
ACTIVITY 6. ENGAGE A SINGLE TARGET WITH THE COAX	●	○
ACTIVITY 7. ENGAGE MULTIPLE TARGETS WITH THE MAIN GUN	◒	●
ACTIVITY 8. ENGAGE TARGETS WITH THE CAL .50	●	○
Option 8.1. Simultaneous Targets	●	○
Option 8.2. Cal .50 Targets	●	○
ACTIVITY 9. ENGAGE TARGET USING DEGRADED GUNNERY TECHNIQUES	◒	○
Option 9.1. Engage Target Using Battlesight Gunnery	◒	◒
Option 9.2. Engage Target Given Ineffective LRF	◒	○
Option 9.3. Engage Target Given Multiple Returns from LRF	◒	◒
Option 9.4. Engage Target Given No Range Display	●	○
Option 9.5. Engage Target Given Crosswind Sensor Failure	◒	○
Option 9.6. Engage Target Given Cant Sensor Failure	◒	○
Option 9.7. Engage Target Given Lead Angle Sensor Failure	○	○

● Device expected to have utility for testing.

◒ Device expected to have only maraginal utility for testing.

○ Device not recommended for testing.

Figure 6-2. Evaluation of device utility for testing tank commander performance (cont'd).

DOMAIN OF ARMOR GUNNERY CREW BEHAVIORS	UCOFT	SIMNET
Option 9.8. Engage Target Given GPS Failure (Day Channel)	○	○
Option 9.9. Engage Target Given GPS/TIS Failure	●	○
Option 9.10. Engage Target Using GAS	●	○
Option 9.11. Engage Target in Emergency Mode	●	○
Option 9.12. Engage Target in Manual Mode	●	○
ACTIVITY 10. ENGAGE TARGET(S) FROM THE TC POSITION	●	◒
ACTIVITY 11. ASSESS RESULTS OF ENGAGEMENT	◒	●

● Device expected to have only marginal utility for testing.

◒ Device not recommended for testing.

○ Device expected to have utility for testing.

Figure 6-2. Evaluation of device utility for testing tank commander performance (cont'd).

DOMAIN OF ARMOR GUNNERY CREW BEHAVIORS	Driver	Loader
ACTIVITY 1. PREPARE STATIONS FOR OPERATION (PREOPS)	○	○
ACTIVITY 2. PERFORM PREPARE-TO-FIRE (PRE-FIRE) CHECKS	◒	○
Option 2.1. Prepare for Offense	◒	○
Option 2.2. Prepare for Defense	◒	○
ACTIVITY 3. ACQUIRE TARGETS	○	○
Part 3.1. Search for Target(s)	○	○
Option 3.1.1. Search Open Hatch - Day	○	○
Option 3.1.2. Search Closed Hatch - Day	○	○
Option 3.1.3. Search at Night	○	○
Part 3.2. Detect/Locate/Identify Target(s)	◒	◒
Part 3.3. Evaluate Situation	N/A	N/A
ACTIVITY 4. ENGAGE SINGLE TARGET WITH THE MAIN GUN	◒	○
Option 4.1. Engage Single Target from the Offense Using Precision Gunnery	◒	○
Option 4.2. Engage Single target from the Defense Using Precision Gunnery	◒	○
Option 4.3. GNR Cannot Identify Announced Target	N/A	○
Option 4.4. Engage Targets Using TIS	○	○
ACTIVITY 5. ADJUST FIRE	◒	○
ACTIVITY 6. ENGAGE A SINGLE TARGET WITH THE COAX	○	○

● Device expected to have utility for testing.

◒ Device expected to have only maginal utilization for testing.

○ Device not recommended for testing.

Figure 6-3. Evaluation of SIMNET utility for testing driver and loader performance.

DOMAIN OF ARMOR GUNNERY CREW BEHAVIORS	Driver	Loader
ACTIVITY 7. ENGAGE MULTIPLE TARGETS WITH THE MAIN GUN	◒	○
ACTIVITY 8. ENGAGE TARGETS WITH THE CAL .50	○	○
Option 8.1. Simultaneous Targets	○	○
Option 8.2. Cal .50 Targets	○	○
ACTIVITY 9. ENGAGE TARGET USING DEGRADED GUNNERY TECHNIQUES	○	○
Option 9.1. Engage Target Using Battlesight Gunnery	◒	○
Option 9.2. Engage Target Given Ineffective LRF	○	○
Option 9.3. Engage Target Given Multiple Returns from LRF	◒	○
Option 9.4. Engage Target Given No Range Display	○	○
Option 9.5. Engage Target Given Crosswind Sensor Failure	○	○
Option 9.6. Engage Target Given Cant Sensor Failure	○	○
Option 9.7. Engage Target Given Lead Angle Sensor Failure	○	○
Option 9.8. Engage Target Given GPS Failure (Day Channel)	○	○
Option 9.9. Engage Target Given GPS/TIS Failure	○	○
Option 9.10. Engage Target Using GAS	○	○
Option 9.11. Engage Target in Emergency Mode	○	○
Option 9.12. Engage Target in Manual Mode	○	○
ACTIVITY 10. ENGAGE TARGET(S) FROM THE TC POSITION	◒	○
ACTIVITY 11. ASSESS RESULTS OF ENGAGEMENT	◒	○

● Device expected to have utility for testing.
◒ Device expected to have only maraginal utility for testing.
○ Device not recommended for testing.

Figure 6-3. Evaluation of SIMNET utility for testing driver and loader performance (cont'd).

incomplete. While this does not diminish their potential importance as devices for practicing tracking skills, they are not strongly recommended for testing in these areas. U-COFT, again not unexpectedly, captures the highest recommendations for testing use. By including a TC station and degraded mode capabilities, a significantly greater portion of the gunnery domain is covered, and it appears to have potential to provide valid scores for gunner and TC skills. SIMNET has some design limitations (e.g., no night simulation, TIS, Coax or Cal .50) that reduce its activity domain coverage, and its configuration (no external monitor dedicated to observing gunner's or TC's sight picture) reduces scoring possibilities. Its greatest potential appears to be for TC testing in Activities 4, 5, 7 and 11. SIMNET driver and loader stations offer little potential for testing skills of these two crew members.

Examination of the conditions evaluations in Appendix F also shows the superiority of UCOFT and SIMNET. VIGS and TopGun provide only the basic variety of conditions needed to support marksmanship training. SIMNET, with its free play format, provides potentially the greatest variety of conditions, particularly with the mission requirements parameters (13 through 18). After considering these evaluations in relation to the element fidelity and domain coverage evaluations, our conclusion was that variations in the representation of secondary conditions was not sufficient to alter our appraisals of device validity. Therefore, the appraisal of secondary conditions carried little weight over the domain coverage analysis.

Automated Feedback Capabilities

Each of the devices does present some type of feedback. However, feedback from none of the devices matches up with our measurement specifications very closely (see the "Automatic Recording" ratings in Appendix I). The data that is provided is mixed. Part of the information may be rather "raw" (e.g. what ammunition was indexed rather than whether the correct ammunition was indexed) and other highly processed (e.g. engagement "points" based on some combination of rounds fired, time and target hit, with a system dispersion factor added in). The emphasis is on speed and target hits with little attempt to tease out the factors that influence hits (e.g., sight picture, range in computer, smoothness of tracking and lead solution, ammunition indexed, and system error). Curiously, there is a tendency to contaminate hit scores with round-to-round dispersion. Certainly, it is appropriate to give crews the experience of rounds missing even when they do everything correctly. On the other hand, scoring and feedback should clearly indicate that the crew indeed performed correctly. TopGun appears to do this. When a round misses due only to a system dispersion factor, lay error registers zero.

Nowhere in our specification of element level measures did we indicate that target hit should be used as an outcome measure. Target hit is a composite measure of crew proficiency. Lay error is provided by U-COFT, VIGS and TopGun, but in each case it appears to be in relation to the projected fall of the round. This index is also a composite score.

It is a product of ammunition indexed, ammunition loaded, correct ranging, and gunners tracking. Any one of these could cause a "lay error." Furthermore, if an incorrect range is entered, or the ammunition selection switch setting does not match the ammunition loaded, then gunner's tracking or lay cannot be evaluated. Our argument is not against hits as a crew outcome criterion measure. Rather, it is for recognition of the fact that number of hits is a score which synthesizes several performance elements, making diagnosis of any single performance element uncertain.

Aside from miss-hit information, SIMNET provides no automated feedback on gunnery performance. The remaining three devices in this respect are described below.

U-COFT. U-COFT provides the most extensive feedback. Gunnery performance is divided into three categories: target acquisition, reticle aim, and system management. These categories are used to define a three dimensional matrix of exercises that systematically vary in difficulty. They are also used to categorize criteria to assess performance on each engagement within the exercises (there are ten targets in each exercise, five to ten engagements depending on whether they are single or multiple target engagements). Thus, a complete description of TC and Gunner proficiency is a combination of exercise score plus level of the exercise in the matrix. Training progress through the matrix is based on exercise scores. Table 6-4 presents the three dimensions and the criteria used to assess performance within each dimension.

Certainly the U-COFT feedback is useful. In addition to letter scores for each of the three dimensions, "raw" data (e.g. time, number, and type of switch errors) is printed in a summary for all of the engagements in an exercise. In addition, there is a dynamic situation monitor that shows switch setting and computer entries, including range. The situation monitor also shows a history of lay errors for the last round fired at each target. These lay errors, as well as the lay errors for all rounds depicted in a shot pattern print-out, are with respect to projected round impact. They are not a straightforward indication of sight picture unless target range in entered perfectly and there are no switch errors. While "lay error" history and switch errors is retained and can be printed out, range entered at the time of firing is not automatically captured. Thus, the U-COFT instructor/operator (I/O) must watch the situation monitor to determine range. From printed materials provided by U-COFT, it is not possible to unequivocally evaluate gunner's tracking skill. On the other hand, it is not particularly difficult for the U-COFT I/O to monitor range or to observe the gunner's sight picture during engagements. Thus, while U-COFT provides useful information, it is not complete in terms of the detailed gunnery domain analysis they we have set forth. Complete diagnostic testing would require additional record keeping by the U-COFT I/O.

Table 6-4

U-COFT Performance Feedback

Skill Dimensions[a]	Criteria[b]
Target Acquisition	Time to acquire target Number of Identification and Classification Errors
Reticle Area	Time to fire first round or burst Time to kill Magniture of main gun aiming error
System Management	Number of switch setting errors before firing Number of switch setting errors at the time of firing.

[a]Skill dimension score is the score of the lowest criterion within the dimension. Possible scores are A, B, C or F.

[b]Each criterion appears on the Performance Analysis printout in raw form (e.g., time, number of errors).

Although we suggest that U-COFT is useful for testing a large portion of the tactical gunnery domain, there is not sufficient information to indicate how U-COFT performance can be translated into performance proficiency on the real equipment. There are several reasons. First, U-COFT performance level, in terms of a crew's position in the matrix progression, is a function of how much the crew has practiced on U-COFT as well as its skill. Highly skilled crews just beginning U-COFT training will be low in the matrix because they have not had time to move up. Second, SMEs using U-COFT have reported some dissatisfaction with the matrix; the order of difficulty of exercises within the of the matrix has recently been adjusted. Third, there is no good external criterion of tactical gunnery to use as a reference. Table VIII measures marksmanship. On the other hand, U-COFT trains primarily marksmanship, so there ought be a relationship between U-COFT and Table VIII scores. At least two studies have examined U-COFT practice and Table VIII scores (Rapkoch & Robinson, 1986; and Hughes, Butler, Sterling, & Berglund, 1987). Only the later study looked at correlations across crews between amount and terminal level of U-COFT practice and Table VIII indices. Correlations were too low to support a conclusion that the U-COFT data and the Table VIII data were measuring the same skills.

VIGS and TopGun. Both of these devices gives "points" based on hits and speed. For either device, it is not possible to determine the comparability of the points across engagements without empirical data. Likewise, it is not possible to project any device point scores into expected performance on real equipment.

Adaptive Testing

None of the devices were designed for adaptive testing. VIGS and TopGun are programmable in that a sequence of engagements can be selected and then presented. Selecting exercises one at a time is time-consuming enough that there is no gain over presenting a series of engagements of varying difficulties. U-COFT, with its large array of exercises, may appear suited to adaptive testing. However, since U-COFT engagements are "packaged" in exercises of 5 to 10 engagements each, selecting engagements means selecting exercises that must then be loaded into the U-COFT computer. Loading, then printing results and unloading exercises take several minutes. Graham (1986) reported that execution of a special 32 engagement test using portions of preselected exercises was "awkward" (p. 5) and resulted in some lost data. Adding branching decisions for adaptive testing to such procedures would only confuse the process further. In summary, adaptive testing does not appear practical for any of the devices.

Conclusions

As simulators, the devices reviewed would be expected to have varying levels of fidelity and inclusiveness. Furthermore, each device may be expected to have some unique operating requirements. For training, this means that personnel may practice on the devices but they must also practice on the real equipment to make the adjustment for the differences between the two. The implications of testing are not as simple. A vehicle operation analogy may illustrate. Most of the skills of driving a car are the same whether the vehicle is a automatic or standard transmission. However, if a person who has learned to drive only cars with automatic transmissions were to take a driving test in a standard transmission vehicle, failing the test would not be surprising. Similarly, if a person who has driven only standard transmission cars drives one with an automatic transmission, the likelihood of attempting to clutch and accidentally hitting the brake pedal while travel 20 to 30 mph may be reasonable high. Unfamiliarity with one type of vehicle or another reduces the expected relationship of performance between the two types. On the other hand, for persons who regularly drive both types, the correlation of driving test scores between the two types would be expected to be quite high.

A similar problem occurs with correlation of simulator performance with real equipment performance. The correlation would be expected to be higher for person who regularly practice on both than for persons who practice on one but not the other. Thus, our evaluations emphasize fidelity (i.e. similarity between device and tank) and are more conservative for testing than for training.

CHAPTER 7

DEVICE-BASED TRAINING AND TESTING STRATEGY

The present chapter combines information from the previous two chapters by assigning training/testing objectives and devices to units of instruction. The outcome of this process is a proposed strategy for training gunnery skills using the designated training devices. In previous chapters we have advocated the interspersing of device-based and on-tank training. That position is maintained. For simplicity, the proposed program presents only the device-based portion of training. We assume that the M1 tank can and should be used for training and practice in all aspects of gunnery.

It should be cautioned at the outset that the training strategy outlined in the present chapter should be regarded as only an initial concept since the training and testing objectives have not been confirmed by external subject matter experts. Should the objectives be modified, it is likely that the overall training strategy will change. The purpose of this proposed concept is to address some of the training design issues early in program development, and to provide a "strawman" for reaction from external sources.

Previous analyses were algorithmic in that they followed specific procedures. In contrast, the process of assigning objectives and devices to blocks of instruction was more heuristic because it was constrained by some general rules of thumb rather than specified by procedural steps. These general rules may be summarized as follows:

1. Specify a generic program. The proposed training strategy was designed to serve as a model for developing any gunnery training program. Consequently, it was not tied to any particular Armor School program of instruction (POI). That is, the program was designed without any assumptions about who is being trained or how much training time is available.

2. Focus on the designated devices. Although there are numerous devices for training gunnery skills, the training strategy was contrived to maximize use of the four computer-based devices that were designated for study in the present project. Additional devices or media were specified only when necessary to provide prerequisites for training on the devices or where the designated devices could not provide the training on aspects of the domain itself.

3. Organize objectives into meaningful units of instruction. The units of instruction should be should be congruent with although not necessarily isomorphic with the partitioning of armor activities (Chapter 2). In other words, there does not have to be a unit of instruction for every activity; nevertheless, instructional units ought to allow practice of meaningful units of behavior as identified in the analysis of behaviors.

4. Specify sequential dependencies between instructional units. The instructional units will be sequenced following the prerequisite relationships identified in the hierarchical analysis. This information will be supplemented with the successive elaboration strategy described in Chapter 4.

5. Be mindful of realistic constraints. Despite its experimental nature, the proposed device-based training program should be constrained by realistic training considerations. A basic constraint is that students and instructors cannot move at will between devices within a single unit of instruction. Therefore, the units specified a single device for instruction of skills. Furthermore, the order in which instructional units are completed should be mindful of real-world constraints, such as the availability of devices and other equipment. Meeting this constraint was facilitated by the similarity in results between the training and testing capabilities evaluations.

6. Prescribe an iterative training strategy. There is considerable overlap in what gunnery devices train. The training strategy should exploit this characteristic to provide multiple experiences on gunnery training objectives in an increasingly realistic context.

The next two sections describe the process as well as the outcome of assigning (a) objectives to units of instruction and (b) devices to units of instruction. Although described separately below, the two processes actually occurred in parallel in order to best meet the criteria described above. The following section provides a discussion of training devices for proficiency measurement outside of the training context.

Assignment of Objectives to Units of Instruction

The hierarchical analysis of gunnery skills described in Chapter 4 revealed a total of 235 training/testing objectives. Of that total, 91 objectives were duplicates of objectives presented elsewhere in the domain. Eliminating these duplicates resulted in 144 unique objectives. Staying mindful of the training objectives and the devices designated for training, we laid out an initial hierarchy of instruction units along with a recommended training medium or device for each unit (see next section). Next, the 144 training/testing objectives were assigned to the units. On the basis of this first attempt, units having too few objectives were subsumed under other topics and units having too many objectives were subdivided. Objectives were reassigned and further refinements to the hierarchy were made until the training strategy appeared both effective and practicable according to guidelines set forth in the previous section. The resulting hierarchy of instructional units is shown in Figure 7-1. To further describe the training concept, Table 7-1 presents the topic of instruction and associated media or devices for each unit. A detailed list of objectives for each unit is provided in Appendix J.

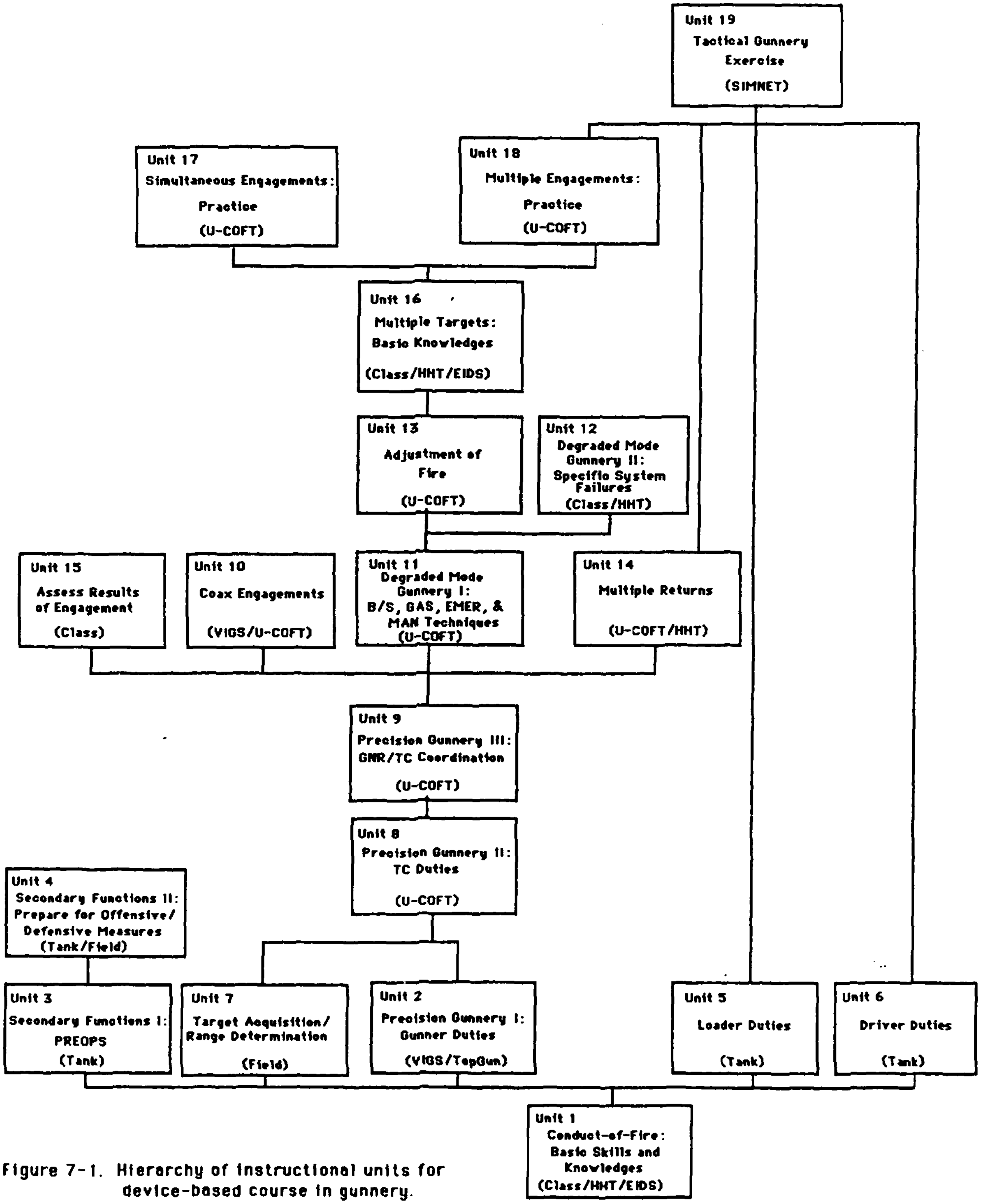

Figure 7-1. Hierarchy of instructional units for device-based course in gunnery.

Table 7-1

Topics and Devices/Media for Instructional Units

Unit Number & Title

1. Conduct of Fire--Basic Skills and Knowledges

Topic:	Basic information on fire commands and operation of gunner controls.
Device/Medium:	Classroom.

2. Precision Gunnery I--Gunner Duties

Topic:	Practice on basic gunner skills (e.g., tracking and lasing) related to precision engagements.
Device/Medium:	VIGS or TopGun.

3. Secondary Functions I--PREOPS Procedures

Topic:	Instruction and practice on preparing gunner, loader, driver, and TC stations for operation.
Device/Medium:	Tank.

4. Secondary Functions II--PREFIRE Procedures

Topic:	Instruction and practice on preparing the tank for combat.
Device/Medium:	Tank in Field Context.

5. Loader Duties

Topic:	Instruction and practice on skills related to loading.
Device/Medium:	Tank.

(table continues)

Unit Number & Title

6. Driver Duties

Topic: Instruction and practice on skills related to driving.

Device/Medium: Tank.

7. Target Acquisition/Range Determination

Topic: Instruction and practice on skills related to target acquisition and range determination.

Device/Medium: Field.

8. Precision Gunnery II--TC Duties

Topic: Practice on basic TC skills (e.g., gun laying and fire commands) related to precision engagements.

Device/Medium: U-COFT.

9. Precision Gunnery III--TC/Gunner Coordination

Topic: Practice for TC and Gunner in coordinating skills related to precision gunnery.

Device/Medium: U-COFT.

10. Coax Engagements

Topic: Instruction and practice on skills related to coaxial machine gun engagements.

Medium/Device: U-COFT or VIGS.

(table continues)

Unit Number & Title	
11. Degraded Mode Gunnery I--B/S, GAS, EMER, & MAN	
Topic:	Instruction and practice on when and how to use the following techniques of degraded mode gunnery: battlesight, gunners alternate sight, emergency mode, and manual mode.
Device/Medium:	U-COFT.
12. Degraded Mode Gunnery II--System Failures	
Topic:	Instruction on what to do in case of failures in the following systems: laser range finder, gunner's primary sight, thermal imagery sight, crosswind sensor, wind sensor, and lead angle sensor.
Device/Medium:	Classroom supplemented with the Hand-Held Tutor.
13. Adjustment of Fire	
Topic:	Instruction and practice on techniques for adjusting fire.
Medium/Device:	U-COFT.
14. Multiple Returns	
Topic:	Practice in recognizing and reacting to multiple returns from the laser range finder.
Medium/Device:	U-COFT.
15. Assess Results of Engagement	
Topic:	Instruction on crew actions performed after a battle engagement.
Medium/Device:	Classroom.

(table continues)

Unit Number & Title

16. Multiple Targets--Basic Knowledges

Topic: Instruction on fire commands and crew actions related to multiple target engagements.

Medium/Device: Classroom supplemented with EIDS.

17. Simultaneous Engagements--Practice

Topic: Practice on skills related to simultaneous engagements.

Medium/Device: U-COFT.

18. Multiple Engagements--Practice

Topic: Practice on skills related to multiple engagements.

Medium/Device: U-COFT.

19. Tactical Gunnery Exercise

Topic: An integrative gunnery exercise in a simulated tactical context.

Medium/Device: SIMNET.

As can be seen in Figure 7-1, the instructional units are numbered from 1 to 19 to identify units as well as to provide a suggested order of presentation. Three aspects of the course sequence should be elaborated upon. First, Unit I (Conduct of Fire) provides instruction on basic skills and knowledges that are prerequisite to every block of instruction. In addition to the specific training objectives, this unit should provide some information on the general flow of activities and basic terminology associated with gunnery. The purpose of this information is to provide "advance organizers" upon which the student may conceptually organize gunnery procedures (Ausubel, 1967). Second, the sequencing was determined by a combination of an successive elaboration strategy (described in Chapter 4) and the prerequisite relationships between units. Note that precision gunnery forms the "trunk" from which most of the elaborative branching occurs. Prerequisites are trained just prior to the elaborative branching to which it pertains. For instance, knowledge prerequisites concerning multiple targets (Unit 16) are trained just prior to training simultaneous and multiple engagements (Units 17 and 18). Third, practical constraints were also considered in sequencing units. For instance, the four units for which the tank was the recommended medium were sequenced together to minimize the logistics required in obtaining the combat vehicle.

As indicated in Appendix J, certain objectives are listed in more than one unit. The purpose of the cross listing was to provide iterative training on the objectives where possible. The model for this iterative training strategy is the crawl-walk-run approach cited in Army training literature. Although typically used to describe three progressive phases of training collective tasks, Drucker and Morrison (1987) provided general criteria for crawl, walk, and run phases that may be applied to individual tasks as well. In the crawl phase of training, a student is introduced to a particular objective. The instructor provides verbal information required to learn the objective and may actually demonstrate task performance. The walk phase of training is characterized by the student's practicing the task to the performance standard. However, the task is practiced in isolation from other related tasks, and the context may not be realistic. Finally, the run stage of training is identified by integrative training wherein tasks are performed with other related tasks in real-time and within realistic contexts. Although these phases of training may be conceptually distinct, it is difficult to classify actual training activities as uniquely typifying one or the other phase of training. Consequently, we did not specify particular training phases for objectives within units. Nevertheless, the proposed training strategy is in keeping with the basic notion behind the crawl-walk-run approach: that objectives be iteratively trained in increasingly realistic contexts.

Assignment of Devices to Instructional Units

Training devices were assigned to the instructional units by considering their capabilities as outlined in Chapters 5 and 6. The device/media assignments are discussed in the following paragraphs.

U-COFT. U-COFT was selected most often (for 8 of the 19 units) as the device of choice for the proposed program. One reason it was chosen was simply because some activities which can be performed on U-COFT cannot be performed on any other device (e.g., simultaneous engagements). In addition, U-COFT offers the highest fidelity and greatest flexibility in terms of instructional features. As stated in Chapter 5, this is not an unexpected result considering the cost and stated purpose of U-COFT.

VIGS/TopGun. For purposes of the present project, VIGS and TopGun are regarded as functionally identical, i.e., they both provide practice on many of the same prerequisite skills. Furthermore, they are both portable (relative to U-COFT and SIMNET), and allow students to practice in full view of the instructor and other observers. Thus, either device would be a useful classroom adjunct. In the proposed program, Precision Gunnery I (Unit 2) immediately follows the Conduct-of-Fire class to allow students to apply some of the concepts that were introduced in the first class as well as practice other prerequisites to precision gunnery. In addition to Unit 2, VIGS may also be useful in introducing students to coax engagements (Unit 10).

SIMNET. In contrast to VIGS and TopGun, SIMNET is designated for use only in the advanced stage of the training program. As revealed in Chapter 5, SIMNET is not well suited to initial training for two reasons: (a) its lack of training features makes it inappropriate to provide repetitive training necessary in the early stages of training; and (b) the fidelity of driving and loading activities is insufficient to support initial training on these skills. On the other hand, SIMNET is well-suited to provide more advanced training in the proposed program for another pair of reasons: (a) it is the only device to simulate many important tactical conditions; and (b) it is the only device that supports full-crew coordination. Consequently, SIMNET was designated as the device to provide the final unit of instruction consisting of an integrative tactical exercise.

Adjunct Devices. Although not the focus of the present study, two devices developed by ARI and the Training Technology Agency (TTA) are designed to promote the acquisition of gunnery-related knowledges. These devices are designated to support or to perhaps substitute for classroom instruction for some of the units. These adjunct "knowledge" devices are briefly described below:

1. The Hand-Held Tutor (HHT) was originally developed by ARI as a small and inexpensive electronic device for providing drill and practice on technical vocabulary. ARI and the Training Technology Field Activity (TTFA) have since modified the HHT to provide training on single- and multiple-target fire commands, degraded mode gunnery, and multiple return strategies.

2. ARI and TTFA have also developed courseware for the TICCIT computer-based/videodisc instructional system. Courseware has been developed on a number of armor subjects, most notably single- and

multiple-target fire commands. Current plans are to convert this TICCIT courseware to the Army-wide system for computer-based/videodisc instruction, the Electronic Information Delivery System (EIDS).

Alternative Media. Chapter 5 noted a number of fidelity problems that contraindicated the use of any of the four devices for training some aspects of the gunnery domain. The following alternative media were designated for those problematic aspects:

1. Tank. The tank is only reasonable medium for training PREOPS and PREFIRE procedures, loader duties, and driver duties. Whereas the PREOPS procedures may be trained on the tank in a motor pool setting, PREFIRE procedures may require access to a range, or at least, a field setting.

2. Field. Target Acquisition/Range Determination (Unit 7) and Prepare for Offense/Defense (Unit 4) should be trained in a field setting. However, a tank may not be necessary to train these objectives.

3. Classroom. In addition to the initial unit on Conduct of Fire, two other units should be trained in a classroom setting:

- The topics covered in Unit 16 (Multiple Targets--Knowledge) may be regarded as a continuation of Unit 1 (Conduct of Fire) in that it deals primarily with fire commands. The reason for splitting this unit from Conduct of Fire is to place it closer to the point in which students may practice the multiple target skills (Units 17 and 18).

- The second unit on degraded mode gunnery (Specific System Failures) consist of degraded modes which cannot be simulated on the devices, e.g., lead sensor system failure. However, the skill required to respond to such failures is minimal, and task performance is more dependent of the knowledge related to detecting the failures themselves. Therefore, the classroom setting may be sufficient to learn these tasks.

Proficiency Testing Outside of Training Context

The above specifications focus on device use in the training context where evaluation of individual or crew performance is considered an integral part of training. Specification of particular devices for the different phases of training therefore implies use of the device for testing as well as for training. On the other hand, proficiency testing does not always occur in the training context. This section presents some concerns about the use of devices to assess gunnery skills outside of training.

An advantage of testing in the training context is that the skill of those being tested is already targeted within the range of the objective level being trained. Outside of the training context, there may be less information about persons' skill levels and so a wider range of skills and objectives must be presented by a test. U-COFT is the only device that

covers an extensive portion of the range of skills. This makes U-COFT the obvious choice of the four devices for determining proficiency levels of gunners and tank commanders. On the other hand, if VIGS or TopGun is fielded at a lower organizational level, availability may make them convenient screening devices for testing gunners.

There are three additional problems that will require further research before any more definitive recommendations can be made for using U-COFT, or any of the other device for testing. First, we have discussed the problem of translating device scores into meaningful "real world" scores (see Chapter 6). Even if the two problems below were solved, there would need to be additional efforts to anchor device scores in terms of an external criterion metric.

Second, the extent to which device unique performance requirements disrupt performance of those without device experience must be determined. As noted in Chapters 5 and 6, in the training context with a mix of device and real equipment training, personnel can learn to adjust to unique device requirements. On the other hand, without such alternating practice, an otherwise competent person may not perform well on an unfamiliar device. As U-COFT training spreads throughout the Army, this will become less of a problem. However, it should be remembered that we are being speculative. Extended studies of U-COFT/M1 performance relationships are still needed.

Third, if U-COFT, or another device, is to be used for proficiency testing, an operational test must be developed. Certainly, the U-COFT library is extensive and one can imagine assembling a test that contains sample engagements from a range of activities and under a vary of conditions. However, actually assembling a test is not as easy. Graham (1986) did string together pieces of several engagements for research purposes and, even in those controlled conditions, found the procedure to be difficult to implement. Thus, current programming of U-COFT training makes efficient testing over the range of skills difficult.

In summary, our current conclusion is that proficiency testing with any of the four devices if it is conducted outside of the training context will be problematic. Therefore no recommendations are being made for stand-alone proficiency testing.

Conclusions

The concept for training and testing indicates that it is feasible to use existing computer-based devices to train and test much of the domain of tank gunnery in an integrated fashion. However, there are gaps in the training program where devices do not support substantial portions of the domain. For instance, none of the devices supported training on target acquisition or degraded mode gunnery for certain system failures. Also, there were cases where basic skills and knowledges were not integrated into higher level training. For instance, the Units 3 and 4 (Secondary Functions) are not integrated into any later instructional units.

Similarly, the skills learned in Unit 17 (Simultaneous Engagements) are not integrated into the final tactical exercise, simply because SIMNET does not support Cal .50 engagements. Consequently, on-tank experience at both the beginning and advanced stages of training is necessary to train and/or test the entire domain of gunnery.

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